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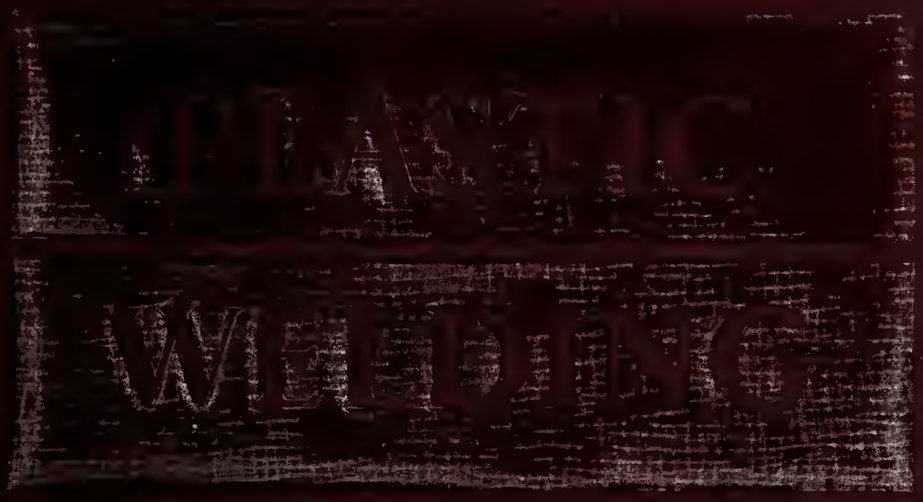

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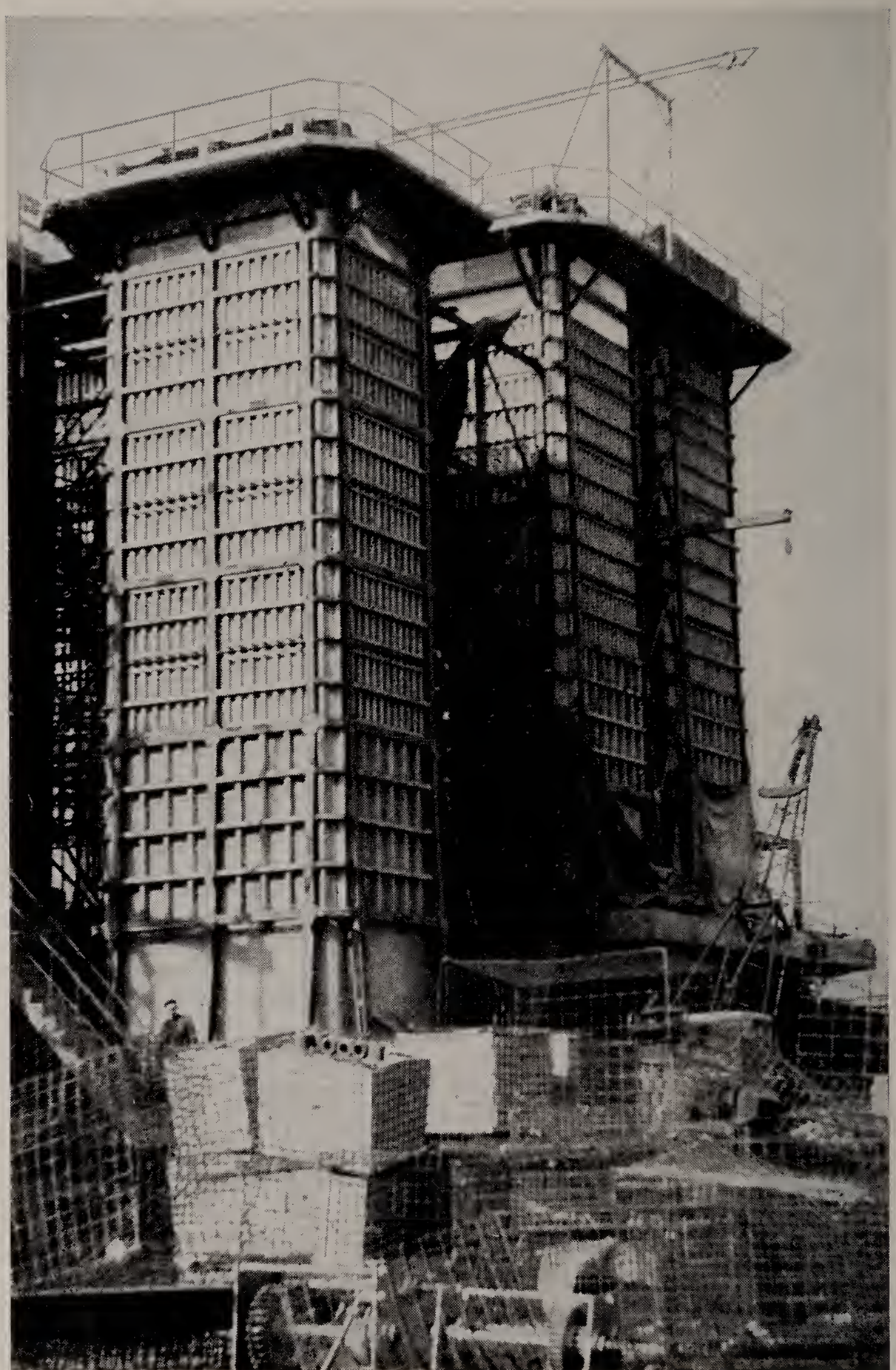
VOL III.—POLYVINYL CHLORIDE



P.V.C. filter tower (in the foreground) and P.V.C. reaction towers in the Kachkaroff Sulphuric Acid Plant, East Midland Coal Board, Chesterfield.

MANUAL FOR PLASTIC WELDING

polyvinyl chloride

by G. HAIM

1960

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TO MY PARENTS

Printed in Great Britain

FOREWORD

by Dr. A. H. Henning

The General Tire & Rubber Company

1117272

In the phenomenally expanding technology of plastics, it is of the utmost importance that the characteristics and properties of individual materials be fully understood so that they can be utilized to their fullest potential and to avoid at the same time the consequences of misapplication and failure.

The title of this book could infer that the reader will be made well acquainted with the welding of plastics, with particular emphasis on polyvinyl chloride. In reality, this book is much more. It is a most complete manual for PVC in general, considering the different ways of its development and application in plastics industries all over the world. Welding, with its historical background and final development, is the principal theme throughout the book. However, to establish the importance of welding, the author, after an historical introduction, develops a comprehensive study of all phases and processes from the basic products to the monomer, polymerization, blending, compounding, modifying and finally the processing and fabrication of the finished product. A wonderful collection of pictures and sketches relates graphically the potential uses of welded PVC in construction, fabrication and applications.

Because of its outstanding properties, PVC is used throughout the world in widely varying amounts and applications. With the development of welding techniques rigid PVC became an important structural material—in fact, the first thermoplastic structural material. The basis requirements for successful and economical application of PVC as a structural material are quality and maximum exploitation of its unique properties. The modern welding techniques make possible constructions very similar to those of weldable metals. However, an adequate knowledge of the material's properties is essential for proper design and applications. Such information is presented here in such a way that this book should prove to be a very valuable tool to everyone who works with PVC from resin production to the final fabrication and installation.

Although emphasis has understandably been placed on the welding of rigid PVC, the author quite satisfactorily discusses the importance

of modern welding techniques in the field of plasticized PVC, which is generally a much simpler procedure.

The author's detailed acknowledgments, extensive references and a list of recommended literature serve as an excellent guide for additional studies beyond the scope of this book.

Here then, is a vital contribution to the technology of PVC.

Akron, Ohio, U.S.A. A. H. HENNING.
April, 1959.

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INTRODUCTION

MOST of the earlier literature concerning the welding and fabrication of polyvinyl chloride was published in German. The shortage of non-ferrous metals after 1933 caused German engineers to look for alternatives which were available on the home market, and they turned, therefore, to thermoplastic materials and, in particular, to polyvinyl chloride. New processes had to be designed to make polyvinyl chloride workable by methods similar to those in use for various non-ferrous metals. In the course of this development a welding process was also invented by Henning. The same process had already been developed by Reinhardt in the U.S.A. a few months earlier on, but due to the fact that there was very little need then to use plastic materials instead of metals in America, Reinhardt's invention disappeared unnoticed in files. Hence the claim that the Germans were the first to develop the welding of thermoplastic materials.

Welding of rigid polyvinyl chloride in Great Britain and the United States was seriously started around 1946, as the basic materials—polyvinyl chloride sheets, pipes and rods—were not available from commercial production at an earlier date.

A great deal of work on welding and fabrication was undertaken in many countries in the post-war years, and rigid polyvinyl chloride in forms suitable for fabrications is nowadays manufactured in most industrial countries.

The apparent lack of basic information in English on this subject led to many requests for translations of German publications and eventually caused the author to write the first book on this subject in English in co-operation with H. P. Zade. This book, *Welding of Plastics*, was published in 1947 and is now out of print. The present book contains some of the information published in *Welding of Plastics* but it is mainly concerned with welding methods and fabrication processes for polyvinyl chloride. It has been written for engineers, works supervisors and welders and it is hoped that it will help to extend the uses of rigid and plasticized polyvinyl chloride.

Chapter XVIII contains the full syllabus of the welding courses which are held in Germany and in the United States of America. It was thought that these details may be of help to principals and teachers of training establishments when they are drawing up the syllabus for their own welding courses.

The literature on Welding and Fabrication of polyvinyl chloride has grown enormously since 1947 and amounts today to well over one

thousand publications and patents. The more important of these are listed in this book which contains references of papers published up to November, 1958.

Many firms have helped by lending photographs, blocks and drawings —their co-operation is acknowledged with great appreciation.

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G. Haim.

Crawley, Sussex.
April, 1959.

CHAPTER I

THE CHEMISTRY AND PHYSICS OF POLYVINYL CHLORIDE

Historical review

Vinyl chloride in its monomeric form was discovered by Regnault in 1838 (*13*), when he treated dichloroethane with alcoholic caustic potash. Regnault also discovered polyvinyl chloride accidentally by exposing the monomer to direct sunlight. Regnault did not realize the importance of his discoveries nor did he realize that the white powder in the sealed glass tube was the polymer of the liquid at first obtained.

Baumann succeeded in 1872 in polymerizing various vinyl halides and he was the first to obtain some of these as a thermoplastic product.

Ostromislensky established in 1912 the conditions for the polymerization of vinyl chloride and developed suitable techniques on a laboratory scale.

Klatte of Griesheim discovered in 1918 the actual process still used for the production of vinyl chloride by reacting hydrogen chloride and acetylene in gaseous form in the presence of catalysts.

Vinyl chloride and its polymers, however, remained laboratory curiosities until the late twenties when real development work on these materials was started almost simultaneously in Germany, the U.S.A. and the U.S.S.R.

Semon (*16*) of the B. F. Goodrich Company and Reid (*14*) of the Carbide and Carbon Chemical Company obtained patents for the production of P.V.C. and these can be considered the starting points for the industrial production of P.V.C.

Many countries took up development work on this material and reasonable tonnages were already produced in pre-war days—with Germany in the lead.

A major discovery in more recent times was Jennings invention (*8*) of the high impact type of polyvinyl chloride.

Basic principles

A multitude of chemical reactions are known for the production of vinyl chloride, but only a few of these will be mentioned in this book. The following basic reactions can be used:

I. Reaction of hydrochloric acid in gas form with acetylene in the presence of metallic or other catalysts.

II. Splitting of HCl from dichloroethane by dehydrochlorination with

alkalies; by thermal dehydrochlorination by catalysed thermal dehydrochlorination. This process can also be achieved by thermal cracking at elevated temperatures. Similar processes can also be used for trichlorethane and symmetric dichloroethane.

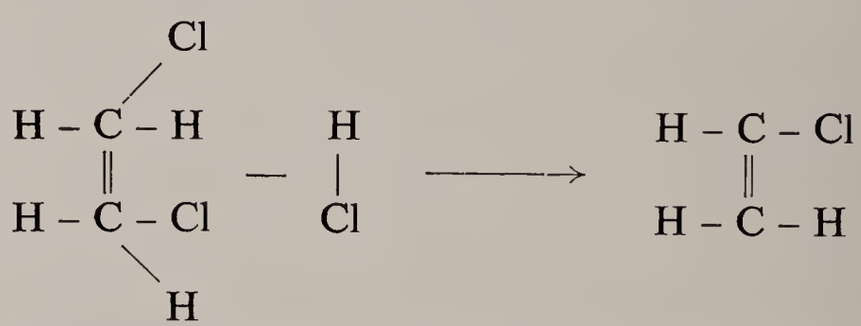
III. Chlorination of ethylene or ethane at elevated temperatures in the presence of catalysts.

Details relating to the various processes can be found in Kainer's book *Polyvinyl-Chlorid und Vinylchlorid-Mischpolymerisate* (*9*). Of all the reactions mentioned only the first two are used for production on a major scale.

Reaction I proceeds in the following manner:

Acetylene + hydrogen chloride ⟶ vinyl chloride (monomer).

Reaction II proceeds as follows:



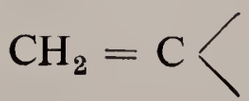
Ethylendichloride – hydrogen chloride → Vinylchloride.

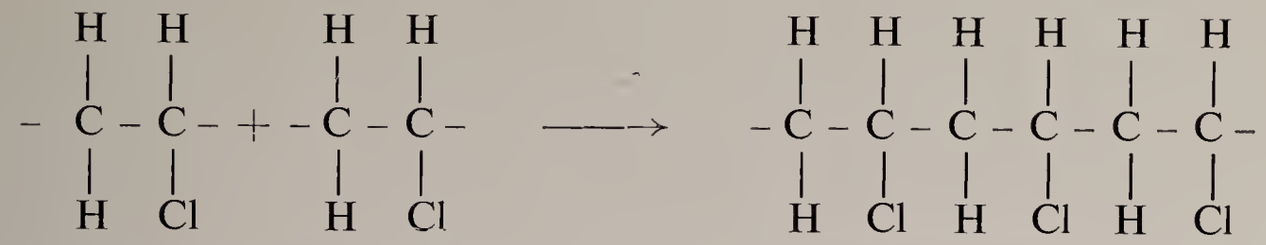
In order to produce suitable polymers, stringent specifications have to be met and it is necessary to purify the monomeric vinyl chloride before polymerization can take place. In the course of this purification process, certain halogenated compounds and traces of the catalysts employed have to be removed. It is also necessary to eliminate traces of acetylene and hydrochloric acid as acetylene prevents polymerization and hydrochloric acid acts as a catalyst in the course of polymerization.

The monomeric vinyl chloride is then subjected to low temperatures to prevent polymerization during storage. Stabilizers may also be added to increase the shelf life of the monomer.

Polymerization

Vinyl chloride contains





Vinyl chloride Polyvinyl chloride

On account of the reactivity of the double bond in the vinyl chloride molecule a plurality of these groups combine together in the course of polymerization to form the polymer molecule. This polymerization process is a chain reaction, which proceeds in three characteristic phases:

First phase: Initiation.

Second phase: Propagation or transfer (formation of nuclei)

Third phase: Chain termination.

The formation of the nuclei is favourably influenced by ultra-violet radiation, heat and by free radicle catalysts. The polymerization process is exothermic in nature, and it is, therefore, necessary to provide cooling—otherwise the process will get out of hand, with disastrous results.

Polymerization of vinyl chloride proceeds in the following way: some of the individual molecules become activated and are thus able to add a large number of monomeric vinyl chloride molecules. New molecules with activated end-groups are thus formed (so-called macro-radicals). This process continues until the reaction is terminated by disproportionation or transfer.

Speed of polymerization

The rate of polymerization can be adjusted by the polymerization conditions which in turn influence the size of the macromolecules formed, i.e. it is possible to tailor polyvinyl chloride so that it yields a material having properties desired for a certain process. Certain chemical compounds when added slow down polymerization; stabilizers stop it altogether. On the other hand, it is also possible to speed up polymerization by radiation with ultra-violet light or light of certain specific wave-lengths. The major means of influencing polymerization are temperature and catalysts.

The polymerization process proper

There are two basically different types of processes which can be used for the polymerization of polyvinyl chloride:

(*a*) Single phase polymerization

(1) without diluent or

(2) in the presence of a diluent

(*b*) two phase polymerization in the presence of water
(1) dispersion or suspension polymerization
(2) emulsion polymerization.

These processes can be initiated either thermally, catalytically, by means of free radical producing compounds, by high intensity radiation or by ultra-violet light.

It is also possible to co-polymerize vinyl chloride with other monomers, the most important of which are vinyl acetate, vinylidene chloride and esters of acrylic and methacrylic acid. By co-polymerization a number of new polymers can be produced, which have very valuable properties.

Of all the different types of polymerization, only the last two, i.e. suspension and emulsion polymerization, are of any importance in the manufacture of polyvinyl chloride. The different polymerization processes yield polyvinyl chloride with varying characteristics.

The properties of polyvinyl chloride, like those of all other polymers, depend mainly on the molecular weight of the polymer, which is determined amongst other factors by the conditions of polymerization, such as temperature, nature and amount of catalyst and solvent employed. The lower molecular weight polymers are soluble in a wide range of solvents but are brittle and discolour when subjected to heat or light. High molecular weight polymers are fairly insoluble in organic solvents and soften at high temperatures. The heat stability of polyvinyl chloride is adversely affected by the presence of low molecular weight polymers. Stability can be improved by co-polymerization.

Polyvinyl chloride is available as a white, finely divided, free-flowing powder, or in the form of pearls; both types are chemically inert and practically insoluble in most of the cheaper solvents. It has good electrical properties and can be processed by a variety of methods into semi-finished and finished products. Almost all these methods are carried out at relatively high temperatures at which polyvinyl chloride tends to decompose; heat stabilizers are therefore added to improve its stability. Plasticizers are also added in many cases to facilitate processing by extrusion, calendering, moulding and casting (slush moulding).

Plasticizers

Definition: plasticizers are either liquids of low volatility or low melting compounds which are added to a thermoplastic material to facilitate processing during moulding, or extrusion. One or several plasticizers may be employed for a particular compound, according to the properties desired for the end product. The actual function of plasticizers is rather complex and for the purpose of this book it may be sufficient to state that plasticizers separate the long chain molecules and lubricate them, so that they slip and slide with comparative ease.

Separation of the molecules greatly reduces the attractive forces emanating from the individual chains and the mere bulk effect of the plasticizer has appreciable effects.

Plasticizers are added to P.V.C. powder or granules before milling or extrusion into pellets; in some cases dry mixing may be carried out just prior to the final extrusion or moulding process.

The correct choice of a plasticizer requires great experience and care. There are no universal plasticizers—and a particular plasticizer may have many desirable features but may have to be ruled out for other reasons, for instance, toxic properties.

The desired properties of plasticizers are the following:

good compatibility with the P.V.C. resin,
low volatility,
freedom from odour and taste,
heat stability,
flame resistance,
stability to ultra-violet light,
chemical inertness,
resistance to extraction by water and other liquids.

Plasticizers should also be non-toxic and have no detrimental effect on the electrical properties of the finished product.

Classification

Several hundred plasticizers are nowadays known and a good many of these can be used for the compounding of plasticized P.V.C. According to American reports nearly 90,000 tons of plasticizers were used in 1953 in the U.S.A. alone with a value of $60,000,000.

Morris (*11*) classified plasticizers in the following way:

phthalates,
phosphates,
low temperature plasticizers, such as sebacates and adipates,
resinous plasticizers,
special purpose plasticizers,
plasticizer extenders.

Bergen, Cowell and Waychoff (*3*) suggest another system of classification. They divide plasticizers into primary plasticizers (phthalates, phosphates, adipates, sebacates, azelates, etc.) and secondary plasticizers also called polymeric plasticizers (polyesters).

Primary plasticizers can be used alone whilst secondary plasticizers are always used together with a primary plasticizer.

Typical examples

Phosphates impart flame resistance and good mechanical properties at low temperatures. A typical plasticizer in this range is tri-2-ethylhexyl phosphate.

Tricresylphosphate (T.C.P. for short) is one of the more widely used plasticizers in the manufacture of soft, plasticized P.V.C.

The technical product nearly always contains some ortho compound, apart from meta- and para-tricresylphosphate. The ortho compound is highly toxic and this is one of the reasons why plasticized P.V.C. containing tricresylphosphate cannot be used for many applications although it yields excellent end products (films and sheet produced from it are noted for good heat stability, freedom from odour and good mechanical properties).

The toxic effect of tricresylphosphate and in particular its effect in plasticized P.V.C. has been described by Berger (*4*).

Tricresylphosphate may also cause eczema—here again the ortho compound is considered to be responsible.

Phthalates

Phthalates are perhaps the most popular plasticizers used for P.V.C. and they amount to 55–60 per cent. of the total volume of plasticizers employed. They yield compounds with very satisfactory properties and can be obtained at economical prices. Typical examples are:

Dibutylphthalate,
Dimethylphthalate,
Diethylphthalate,
Diphthalates of Fischer Tropsch Alcohols,
Dioctylphthalate.

Dimethylphthalate has a high volatility—dioctylphthalate a very low one. Some of the phthalate plasticizers impart a sweetish smell to the end product—they are excellent plasticizers especially for clear (transparent) film and foil.

Resinous plasticizers are chosen for their very low volatility and resistance to extraction.

Hexanetriolesters of fatty acids from the Fischer Tropsch Process, yield compounds which are of outstanding flexibility at low temperatures—but they have a rancid smell which is rather objectionable.

Water absorption and plasticizer losses in plasticized P.V.C.

Investigations concerning the absorption of water and the leaching out of plasticizers in soft (plasticized) P.V.C. films and foils were carried out by Beck (*1*), who used emulsion type polymers and a variety of plasticizers, including tricresylphosphate, diphthalates of Fischer Tropsch Alcohols, dioctylphthalate and a few others. Beck came to the following conclusions:

Water absorption and plasticizer losses are considerably greater in cast P.V.C. films than in calendered films or in films which have been gelled under pressure.

The emulsifier is rather quickly leached out in the case of compounds containing fatty acid plasticizers and the leaching out of plasticizers and the absorption of water soon comes to an end (i.e. equilibrium is reached).

Reduction in plasticizer content of the compound reduces water absorption.

Stationary tests show lower figures than tests carried out with freely flowing liquids.

Migration of plasticizers

Plasticizer migration is defined as a process during which one or more plasticizers migrate from a plasticized polymer into a polymer containing less or no plasticizer at all; it is, of course, obvious that both polymers must be in direct contact—for instance, two sheets of two different thermoplastic material sandwiched together.

A variety of factors determine the rate of migration, i.e.

the molecular structure of the polymers,
the molecular structure of the plasticizer and any reciprocal effects between these,
the concentration of the plasticizer,
and last, but not least, the temperature.

Beck and Rosenberg (*2*) carried out some investigations to ascertain the migration of plasticizers from P.V.C. into nitrocellulose foil—a particular case which is not of much interest within the scope of this book, but the fundamental findings can equally well be applied to other systems. A method to determine the speed of migration of plasticizers was given by Rössig who investigated a system rigid P.V.C.—plasticized P.V.C.—rigid P.V.C. at 40° C. (*15*).

The migration of plasticizers is of considerable interest for laminated materials, for instance, sheets consisting of a sandwich (plasticized P.V.C./unplasticized P.V.C.), see page 46. The success in this case depends on the proper ratio between the two sheets, i.e. $\frac{1}{3}$ plasticized material (or less) and $\frac{2}{3}$ rigid sheet. Where this ratio is exceeded more plasticizer will migrate into the rigid sheet before equilibrium is reached, resulting in reduced mechanical strength of the rigid part of the laminate.

Stabilizers

Stabilizers are added to P.V.C. compounds for two reasons; to prevent thermal degradation of the material during extrusion, moulding, etc., and to retard the effect of heat and ultra-violet light.

Opinions differ about the proper choice of stabilizers; they can be classified into inorganic and organic stabilizers. Plasticizers and fillers influence to some extent the behaviour of a particular stabilizer and it may happen that a stabilizer which is quite satisfactory in many

cases, no longer works due to a particular plasticizer or filler. Some phosphoric acid plasticizers for instance, have a detrimental effect on some organic stabilizers.

Thermal degradation of P.V.C. is a reaction which proceeds in steps. At first two neighbouring C-atoms split off HCl, and the HCl so formed has a catalytic effect, especially in the presence of heat and ultra-violet light. Discolouration takes place and the material changes from white into yellow, to brown, to red and finally becomes black. Ultra-violet light, pressure and heat favour oxydation. Iron, tin and cadmium act as catalysts. Degradation of P.V.C. is caused by two simultaneous processes, splitting of HCl and oxydation.

A stabilizer has the following functions:

it should prevent formation of HCl,
it should neutralize HCl formed,
it should saturate double bonds,
it should prevent oxydation,
it should protect the compound against ultra-violet light.

Stabilizers are, therefore, either heat or light stabilizers, but there may be a combined effect.

The most common stabilizers are lead stabilizers, such as lead oxide, lead carbonate, lead stearate, lead silicate, etc. Lead stearate may cause a blooming effect and one has to be careful regarding the quantities to be added. Lead stearate also acts as a lubricant.

For transparent products lead stabilizers are unsuitable, and tin-based stabilizers are preferred.

Earlier types of German P.V.C. were stabilized with sodium bicarbonate, sodium phosphate or urea compounds. These stabilizers are not very effective and German P.V.C. was therefore, supplied in a wide range of colours varying from fawn to dark brown.

The amount of stabilizer depends on the compound and manufacturing process used and varies from 3–7 per cent.

Proper design of the processing equipment, especially the die-system of an extruder, can greatly help to overcome degradation and thus reduce the amount of stabilizer to be added (*6*).

Ageing of polyvinyl chloride

Havens (*7*) reported that polyvinyl chloride discolours as a result of thermal degradation and that this effect becomes noticeable even if only as little as ·01 per cent. of the material becomes decomposed. At 130° C. HCl, H_2SO_4 and phenol increase degradation at a fast rate, whilst nitrogen, air and oxygen have little influence.

The degradation of unstabilized P.V.C. due to ultra-violet light becomes first noticeable by a fading in colour of the P.V.C.; eventually insoluble cross-linked polymers are formed. Degradation proceeds faster in the presence of HCl.

Fillers

Fillers are often used in P.V.C. compounds. The following have been used with varying success: asbestos, mica, lead and zinc oxide, titania, graphite, carbon black and woodflour.

Compounds of rigid (unplasticized) P.V.C. containing up to 30 per cent. of graphite can be extruded into pipes and rods without great difficulty. The finished product is obviously black in appearance and can be used for heat exchangers (because of its very much higher heat transfer coefficient). Pipes so produced are ideal for electrostatic precipitation plant—where good conductivity and high resistance to chemicals are required.

Rigid P.V.C. pipes containing TiO_2, MgO or ZnO have occasionally been shown on exhibitions; they have apparently not been a success and have been withdrawn.

P.V.C. flooring in factories producing nitroglycerine and other explosives must be conductive to prevent electrostatic discharges and sparking. Compounding of the flooring material with sufficient graphite and laying of metal wires underneath the flooring yields satisfactory floors for this particular application.

Solvents

Quite a few solvents are known for polyvinyl chloride but in general they are not very satisfactory especially for higher molecular weight types of P.V.C.

Alcohol, petrol and mineral oils do not dissolve P.V.C. Esters, ketones, aromatic hydrocarbons and most chlorinated hydrocarbons have a swelling effect on P.V.C. or dissolve it.

The more commonly used solvents for P.V.C. are the following:

Cyclohexanone
Methylene chloride
Cyclopentanone
Mixtures of acetone and benzene or trichlorethylene
Chlorobenzene
Chlorotoluene
Furfurylalcohol.

An excellent solvent for P.V.C. especially for high molecular weight polymers is tetrahydrofurane.

The solubility of P.V.C. can be improved by post-chlorination.

Post-chlorinated polyvinyl chloride

Ordinary polyvinyl chloride types do not dissolve in the cheaper solvents; but chlorination of polyvinyl chloride in solution (tetrachloroethane) at approximately 50° C. yields a product with a chlorine content of approximately 60 per cent. chlorine, soluble in methylene chloride, butyl acetate and acetone.

Post-chlorinated P.V.C. is at the present time only produced in Germany; it is sold under various trade names such as Vinoflex, Igelit PC and Vinifol. It can be used for corrosion resistant lacquers and cements, but the main application is the manufacture of the so-called PeCe fibres for P.V.C. filter cloth and yarn.

Resistance of Rigid, Unplasticized Polyvinyl Chloride to Chemicals

Most plastic materials, like any other material, are liable to some attack by chemicals. This attack, however, is in general very much less severe than with metals, and this is an important factor in the widespread and rapid growth in the use of plastics in industry.

The resistance of polyvinyl chloride to chemicals has already been investigated in the earlier stages of development and comprehensive tables have been published by Krannich (*10*) and others. These tables have been revised on several occasions and those given in this book are up-to-date; they are offered for general guidance, but as conditions vary from application to application, confirmatory tests should be carried out in doubtful cases before undertaking large projects.

The chemical attack on polyvinyl chloride proceeds in stages different from those familiar in the corrosion of metals. In the case of metals certain chemical reactions take place mainly on the surface. The speed of reaction depends on the formation of protective layers which may reduce the corrosion or prevent it altogether. Part of the material is dissolved with a consequent loss in weight; this loss in weight related to time and surface area under consideration can be converted to a 'corrosion rate' and expressed in $g/cm^2/day$ or in mm/year.

In the case of plastic materials corrosion or attack is not necessarily caused by a chemical reaction; the attacking liquid or a gas penetrates into the material, i.e. the attack does not take place on the surface but inside the material, consequently the material does not lose in weight; on the contrary its weight and its volume increase and the material swells until a saturation point is reached.

This swelling effect can be specified in relation to the surface area and time and it can be given as 'swelling speed' in $g/m^2/day$. It can also be quoted in the form of maximum swelling in g/cm^3, i.e. reference is made to the volume.

In specific cases where part of the material is dissolved, this will obviously be indicated by a loss of weight.

This difference in behaviour may be explained by a difference in the molecular structure between metals and plastic materials. Liquids do not penetrate into the interior of metals due to their very much closer molecular structure, whilst gases sometimes diffuse through metals. In the case of plastic materials with their very much wider lattices, penetration of liquids and gases (diffusion) often takes place.

Swelling due to the penetration of a liquid into polyvinyl chloride may proceed in a variety of ways. Water, for instance, will penetrate without causing the swelling of individual molecules; very small globules of water will agglomerate causing the material to become cloudy or milky in appearance. Prolonged immersion in water may lead to further agglomeration of the individual droplets of water which eventually may become visible to the naked eye, particularly so in laminated sheets or blocks. Each individual droplet causes a notch effect on the material and this leads to reduced mechanical properties.

Swelling due to water absorption is much more pronounced in the case of P.V.C. emulsion polymers (some of the emulsifying agents retained will be dissolved and replaced by water); P.V.C. suspension polymers are less liable to water absorption and this is one of the reasons why suspension polymers are nowadays preferred for the manufacture of P.V.C. sheet, blocks, rods and pipes.

Organic solvents also attack polyvinyl chloride to a certain degree, but in this case the solvent penetrates into the molecules proper, a process which is called 'solvatation'. The material softens considerably and its elongation increases. If the material is removed from the solution and left to dry on its own, or if the drying is forced by application of heat, the solvent will evaporate and the original properties of the material will be restored in the majority of cases. In others, however, this may lead to delamination.

Swelling by water or even more so by solvents is increased by simultaneous application of heat as can be proved by boiling a piece of rigid polyvinyl chloride in water, when the sample under test will quickly become milky or cloudy for the full depth immersed.

In addition to swelling, chemical attack may also take place; for instance, oxidizing agents such as hot concentrated nitric acid, hot concentrated sulphuric acid (98 per cent. or over), etc., may partly oxidize the material and lead to its destruction, although this effect is usually very slow.

Stress cracking (environmental cracking)

Rigid polyvinyl chloride, like most thermoplastic materials, is liable to stress-cracking when immersed in certain liquids. This phenomenon was first reported by Nitsche and Esch (*12*) and later on by Krannich (*10*).

Stress-cracking is, however, much less pronounced than in the case of polythene and acrylates; nevertheless, it may cause serious failures. Nitsche and Esch reported a case where localized swelling of a polyvinyl chloride tank lining caused stress cracks around the level of the liquid in the tank. The P.V.C. lining was subject to swelling for its full immersed length and this obviously led to an increase in volume or thickness of the lining. This abrupt change in thickness caused notch effects and stress concentrations around the liquid level, eventually leading to stress cracks.

Specific examples:

Water: Rigid polyvinyl chloride shows very little swelling when in contact with water up to a temperature of 105° F. (40° C.). Prolonged immersion in water at higher temperatures leads to pronounced swelling and absorption of water, although this effect is not very serious up to a temperature of approximately 140° F. (60° C.).

Salt solutions: It is interesting to note that the water absorption of rigid polyvinyl chloride decreases with increasing salt content of the solution. Buchmann (*5*) reported that P.V.C. immersed in a 15 per cent. sodium chloride solution at 120° F. (50° C.) gave approximately the same water absorption figures as pure water at 105° F. (40° C.). A 30 per cent. sodium chloride solution tested at 140° F. (60° C.) equalled the absorption figures of water at 105° F. Many other salt solutions behave in a similar way. There are exceptions to this rule, for instance, strongly oxidizing salt solutions which will attack more severely when in more concentrated form.

Acids: Most inorganic acids show a similar effect; i.e. more concentrated acids cause less attack than dilute acids; here again oxidizing acids behave differently.

Alkalies: Alkali solutions, even in concentrated form show the same behaviour as neutral salt solutions, i.e. the attack becomes in general less severe as the concentration of the solution increases.

Gases: Dried gases, such as ammonia, CO_2, oxygen, SO_2, sulphuretted hydrogen and the like have very little effect on rigid P.V.C. Moist gases or their condensates affect rigid P.V.C. according to the list shown below. Oxidizing gases, for instance nitrous oxide in concentrated form, attack P.V.C. especially in areas with stress concentrations.

Solvents: Aromatic hydro carbons and chlorinated hydro carbons have a considerable swelling effect on rigid P.V.C.; some of these may even dissolve part of the material. The effect is less noticeable at low concentrations.

TABLE I

RESISTANCE OF RIGID, UNPLASTICIZED P.V.C. TO CHEMICALS
(All specimens tested were unstressed)

Agent	*Concentration*	*Temperature* 70° F.	140° F.
Acetaldehyde	40 per cent.	*	0
Acetaldehyde	100 per cent.	–	–
Acetic acid	1–25 per cent.	*	0
Acetic acid	25–60 per cent.	*	0
Acetic acid	80 per cent.	0	–
Acetone		–	–
Adipic acid		*	0

*=suitable; –=unsuitable; 0=some attack or absorption.

Agent	*Concentration*	*Temperature* 70° F.	140° F.
Aluminium chloride solution	dilute	*	0
Aluminium chloride solution	concentrated	*	*
Aluminium sulphate solution	concentrated	*	*
Allyl alcohol		0	–
Alum	concentrated	*	*
Ammonia	gas 100 per cent.	*	*
Ammonia	liquid 100 per cent.	0	0
Ammonium chloride	saturated	*	0
Ammonium fluoride	20 per cent	*	0
Ammonium hydroxide	·880 s.g.	*	*
Ammonium nitrate	saturated	*	0
Ammonium sulphate	saturated	*	*
Ammonium sulphide	saturated	*	*
Amyl acetate	100 per cent	0	–
Aniline	100 per cent	–	–
Aniline hydrochloride	saturated	–	–
Anthraquinone sulphuric acid		*	–
Antimony chloride		*	0
Arsenic acid		*	0
Benzaldehyde		0	–
Benzene		–	–
Benzine		*	*
Benzine/benzene	80/20	–	–
Benzoic acid		*	0
Bleach lye	12 per cent. free chlorine content	*	0
Borax	cold saturated	*	*
Boric acid	dilute	*	0
Boric acid	concentrated	*	0
Bromic acid	10 per cent.	*	
Bromine gas	weak concentration	*	
Bromine liquid	100 per cent.	–	–
Bromine water		*	0
Butadiene	100 per cent.	*	*
Butanediol	10 per cent.	*	0
Butanediol	60 per cent.	–	–
Butanediol	100 per cent.	–	
Butyl acetate	100 per cent.	–	–
Butyl alcohol	100 per cent.	*	0
Butyric acid	20 per cent.	*	0
Butyric acid	concentrated	–	–
Calcium chloride	saturated cold	*	*
Calcium hypochlorite (Bleach sol.)		*	*
Calcium nitrate	50 per cent. solution	*	0
Carbon dioxide	100 per cent. dry	*	*
Carbon dioxide	100 per cent. wet	*	0
Carbon dioxide	cold saturated solution	*	0
Carbon disulphide		0	–
Carbon tetrachloride	100 per cent.	0	–

*=suitable; –=unsuitable; 0=some attack or absorption.

Agent	*Concentration*	*Temperature* 70° F.	140° F.
Chloric acid	1–20 per cent. aq.	0	0
Chlorine dry gas	100 per cent.	*	0
Chlorine moist gas		0	
Chlorine liquid		–	–
Chlorine water		0	0
Chlorsulphonic acid		0	–
Chromic acid	up to 50 per cent.	*	*
Chromic acid with sulphuric acid		*	*
Citric acid	10 per cent.	*	0
Citric acid	saturated	*	*
Coconut oil alcohols		*	*
Copper fluoride	2 per cent.	*	*
Copper sulphate	dilute	*	0
Copper sulphate	saturated	*	*
Cresol	up to 90 per cent. conc.	0	–
Cuprous chloride	saturated	*	0
Cyclohexanol		–	–
Cyclohexanone		–	–
Dextrin	saturated solution	*	0
Dibutylphthalate		0	0
Diethylene glycol		*	*
Ethyl acetate	100 per cent.	–	–
Ethyl acrylate	100 per cent.	–	–
Ethyl alcohol		*	0
Ethyl ether		–	–
Ethylene chloride		–	–
Ethylene dichloride		–	–
Ethylene glycol		*	–
Fatty acids		*	*
Ferric chloride	saturated	*	*
Ferrous sulphate		*	*
Fluosilicic acid	up to 32 per cent.	*	*
Formaldehyde	40 per cent.	*	0
Formic acid	50 per cent.	*	0
Formic acid	concentrated	*	–
Fruit pulp		*	*
Fuel oils		0	0
Glucose	cold saturated	*	0
Grape sugar	cold saturated	*	*
Glycerine		*	*
Glycol		*	*
Glycollic acid	37 per cent.	*	*
Hydrobromic acid	50 per cent.	*	*
Hydrochloric acid	10 per cent.	*	*
Hydrochloric acid	30 per cent.	*	*
Hydrochloric acid	35 per cent.	*	*
Hydrochloric acid	over 35 per cent.	*	*
Hydrofluoric acid	40 per cent.	*	0
Hydrofluoric acid	60 per cent.	0	0

*=suitable; –=unsuitable; 0=some attack or absorption.

Agent	*Concentration*	*Temperature* 70° F.	140° F.
Hydrofluoric acid	concentrated	0	0
Hydrogen		*	*
Hydrogen bromide	10 per cent.	*	–
Hydrogen chloride gas	dry	*	*
Hydrogen peroxide	up to 30 per cent.	*	0
Hydrogen phosphide		*	0
Hydrogen sulphide		*	0
Ketones		–	–
Lactic acid	10 per cent.	*	0
Lactic acid	90 per cent.	–	–
Lead acetate	saturated	*	*
Lead tetra-ethyl	100 per cent.	*	*
Linseed oil		*	*
Magnesium chloride	saturated	*	*
Magnesium sulphate	cold saturated	*	*
Maleic acid	saturated	*	0
Methyl alcohol	100 per cent.	*	0
Methyl bromide		0	–
Methyl chloride		0	–
Methylene chloride	100 per cent.	–	–
Methyl methacrylate	100 per cent. monomer	–	–
Milk		*	*
Mineral oils		*	*
Molasses (commercial)		*	*
Monochloroacetic acid	100 per cent.	*	0
Nickel sulphate	saturated	*	*
Nicotine	dilute	*	
Nitric acid	1–30 per cent.	*	0
Nitric acid	30–50 per cent.	*	0
Nitric acid	50–60 per cent.	*	0
Nitric acid	70 per cent.	*	0
Nitric acid	95 per cent.	–	–
Nitric acid	concentrated 98 per cent.	–	–
Octyl cresol		0	0
Oils & Fats (vegetable)		*	0
Oleic acid		*	*
Oxalic acid	dilute	*	0
Oxalic acid	saturated	*	*
Oxygen		*	*
Ozone		*	*
Petrol (free from aromatics)	100 per cent.	*	*
Petrol-Benzene-mixture	80/20	–	–
Perchloric acid	10 per cent.	*	0
Phenol	90 per cent.	0	0
Phenylhydrazine	100 per cent.	–	–
Phosgene (gas)	100 per cent.	*	*
Phosphoric acid	Up to 30 per cent.	*	*
Phosphoric acid	Over 30 per cent.	*	*

*=suitable; –=unsuitable; 0=some attack or absorption.

Agent	*Concentration*	*Temperature* 70° F.	140° F.
Phosphoric acid	90 per cent.	*	*
Phosphorus (yellow)	100 per cent.	*	
Phosphorus pentoxide	100 per cent.	*	
Phosphorus trichloride	100 per cent.	–	–
Photographic developers		*	*
Photographic emulsions		*	*
Photographic fixing solution		*	*
Picric acid	1 per cent.	*	
Potassium borate	1 per cent.	*	*
Potassium bromate	10 per cent.	*	*
Potassium bromide	saturated	*	*
Potassium chloride	saturated	*	*
Potassium chromate	40 per cent.	0	–
Potassium cyanide	saturated	*	*
Potassium dichromate	40 per cent.	*	*
Potassium ferri/ferro cyanide	saturated	*	*
Potassium fluoride		*	0
Potassium hydroxide	concentrated	*	*
Potassium nitrate	saturated	*	*
Potassium permanganate	up to 18 per cent.	*	0
Potassium persulphate	saturated	*	0
Propane liquid and gas		*	0
Pyridine		–	–
Sea water		*	*
Silicic acid		*	*
Silver nitrate solution		*	0
Soap solution		*	*
Sodium benzoate	35 per cent.	*	0
Sodium bisulphite	saturated	*	*
Sodium borate		*	*
Sodium bromide		*	*
Sodium chlorate	saturated	*	0
Sodium chloride	saturated	*	*
Sodium hydroxide	concentrated	*	*
Sodium nitrate		*	*
Sodium sulphide	saturated	*	*
Stannous chloride		*	0
Starch solution (commercial)		*	*
Stearic acid	100 per cent.	*	*
Sulphur dioxide	dry 100 per cent.	*	*
Sulphur dioxide	wet 100 per cent.	*	0
Sulphur dioxide	liquid	0	–
Sulphuric acid	up to 40 per cent.	*	*
Sulphuric acid	40–80 per cent.	*	*
Sulphuric acid	80–90 per cent.	*	*
Sulphuric acid	96 per cent.	*	0
Sulphuric acid	98 per cent.	0	0
Sulphuric acid, fuming		–	
Sulphurous acid		*	

*=suitable; –=unsuitable; 0=some attack or absorption.

Agent	*Concentration*	*Temperature* 70° F.	140° F.
Tallow		*	*
Tanning extracts	normal concentration	*	
Tartaric acid	10 per cent.	*	*
Tartaric acid	saturated	*	*
Toluene		–	–
Transformer oil		*	*
Trichloroethylene		–	–
Turpentine		*	
Urea	up to 30 per cent.	*	*
Vinegar		*	0
Vinyl acetate	100 per cent.	–	
Water		*	*
Wines		*	
Xylene		–	–
Yeast		*	*
Zinc chloride	saturated	*	*
Zinc sulphate		*	*
MIXTURE OF ACIDS			
Chromic/sulphuric/water			
400 10 1,000		*	0
25 200 1,000		*	0

*=suitable; –=unsuitable; 0=some attack or absorption.

Chemical Resistance of Plasticized Polyvinyl Chloride

The chemical resistance of plasticized P.V.C. depends on a variety of factors, and specific recommendations concerning its suitability cannot be made without knowing the applications.

Plasticized P.V.C. stands up well to water, including sea water, salt solutions, most oxidizing and reducing agents and to dilute acids and alkalies at ambient temperatures. The plasticizer sometimes hydrolizes at higher temperatures and a certain amount of it may also be leached out. This is, however, not necessarily of great importance as equilibrium is often reached at an early stage when the formation of an unplasticized or less plasticized layer on the surface of the sheet or coating prevents further leaching out.

Concentrated acids and alkalies slowly hydrolize most plasticizers in the cold, although this reaction may be extremely slow but becomes more pronounced at higher temperatures.

Organic solvents, oils, paraffin and petrol also extract plasticizers; special grades of plasticized P.V.C. are available for petrol and concentrated hydrogen peroxide (H.T.P.).

An important field for plasticized P.V.C. is that of tank linings for the plating industry. This material shows a better resistance to practically all commercial plating solutions than rubber, neoprene and the like.

Table II

Resistance of Plasticized P.V.C. to Chemicals

(The data given refer to a commercial compound containing 60 per cent. P.V.C. and 40 per cent. tricresyl phosphate)

Agent	*Concentration*	*Maximum Temperature Limit °F.*	*Rating*
Acetic acid	10 per cent.	170°	*
Acetic acid	30 per cent.	170°	*
Acetic acid	50 per cent.	170°	*
Acetic acid	100 per cent.	70°	–
Acetone	all concentrations	70°	–
Alum (potassium)	saturated	180°	*
Aluminium chloride	saturated	180°	*
Ammonia	10 per cent.	180°	*
Ammonia	28 per cent.	140°	*c.c.
Ammonium chloride	saturated	180°	*
Ammonium sulphate	saturated	180°	*
Aniline hydrochloride	10 per cent.	140°	0
Arsenic acid	30 per cent.	180°	*
Benzene	100 per cent.	–	–
Benzoic acid	saturated	180°	*
Bisulphite (sodium)	dilute	140°	*
Bleach (hypochlorite)	15 per cent. av. Cl.	140°	*c.c.
Borax	saturated	170°	*
Boric acid	saturated	140°	*
Brass plating solution		180°	*
Bright nickel plating solution		180°	*
Bromine (gas or liquid)		70°	–
Butadiene	100 per cent.	70°	–
Butyl alcohol	100 per cent.	70°	–
Butyric acid	100 per cent.	70°	–
Calcium chloride	saturated	180°	*
Carbon dioxide	100 per cent.	180°	*
Carbon tetrachloride	pure	100°	0c.c.
Chlorine gas (dry)		160°	*
Chlorine gas (wet)		160°	0
Chromic acid	10 per cent.	160°	*
Chromic acid	30 per cent.	120°	*
Chromic acid	50 per cent.	100°	0
Citric acid	50 per cent.	180°	*
Copper sulphate	saturated	180°	*
Cyanide cadmium plating solution		180°	*
Cyanide copper plating solution		180°	*
Dextrine	saturated	180°	*
Diesel oil		140°	0
Di-Sodium phosphate	saturated	180°	*
Ethyl acetate	pure	20°	–
Ethyl alcohol	96 per cent.	20°	–

*=suitable; 0=some attack; c.c.=colour change; –=unsuitable.

Agent	*Concentration*	*Maximum Temperature Limit °F.*	*Rating*
Ethyl alcohol	pure	120°	–
Ethyl ether	pure	120°	–
Ethylene glycol	pure	120°	0
Fats (animal and vegetable)		70°	0
Ferric chloride	saturated	180°	*
Fixing solution		70°	*
Fluoboric acid	saturated	180°	*
Formaldehyde	37 per cent.	120°	0c.c.
Formic acid	85 per cent.	180°	*
Glucose	saturated	70°	*
Glycerine	pure	140°	*
Gold plating solution		180°	*
Hard chromium plating solution		150°	*c.c.
High speed copper plating solution		180°	*
Hydrobromic acid	50 per cent.	120°	0c.c.
Hydrochloric acid	10 per cent.	180°	*
Hydrochloric acid	20 per cent.	160°	*
Hydrochloric acid	35 per cent.	140°	*c.c.
Hydrofluoric acid	5 per cent.	160°	*
Hydrofluoric acid	48 per cent.	100°	0
Hydrofluosilicic acid	10 per cent.	180°	*
Hydrogen peroxide	3 per cent.	160°	*
Hydrogen peroxide	95 per cent.	70°	*
Indium plating solution		180°	*
Lactic acid	90 per cent.	140°	*
Lead acetate	dilute	70°	0
Lubricating oil		70°	0
Magnesium salts	saturated	180°	*
Mercuric chloride	saturated	180°	*
Methyl alcohol	100 per cent.	70°	–
Methylene chloride	100 per cent.	70°	–
Methyl-ethyl-ketone	pure	70°	–
Nickel salts	saturated	180°	*
Nitric acid			
Nitric acid	10 per cent.	170°	*
Nitric acid	30 per cent.	150°	*
Nitric acid	50 per cent.	100°	*
Nitric acid	70 per cent.	100°	0
Nitric acid Hydrofluoric acid	15 – 4 per cent.	160°	*
Nitroglycerine	100 per cent.	70°	–
Oxalic acid	saturated	160°	*
Perchloric acid	concentrated	120°	*
Petrol	pure	70°	–
Phenol	5 per cent.	140°	*
Phosphoric acid (ortho.)	85 per cent.	180°	*
Phosphorous pentoxide	100 per cent.	70°	*
Picric acid	saturated	160°	*
Potassium cyanide	saturated	180°	*

* =suitable; 0 =some attack; c.c. =colour change; – =unsuitable.

Agent	*Concentration*	*Maximum Temperature Limit °F.*	*Rating*
Potassium dichromate	saturated	180°	*
Potassium ferrocyanide	saturated	180°	*
Potassium hydroxide	5 per cent.	180°	*
Potassium hydroxide	10 per cent.	180°	*
Potassium hydroxide	30 per cent.	160°	*
Potassium hydroxide	50 per cent.	70°	0
Potassium persulphate	saturated	100°	*
Pyrogallic acid	20 per cent.	180°	*
Rhodium plating solution		180°	*
Sea water		180°	*
Silver nitrate	saturated	180°	*
Silver plating solution		180°	*
Sodium bisulphite	saturated	140°	*
Sodium borate	saturated	140°	*
Sodium chloride	saturated	180°	–
Sodium cyanide	saturated	180°	*
Sodium hydroxide	5 per cent.	180°	*
Sodium hydroxide	10 per cent.	180°	*
Sodium hydroxide	30 per cent.	160°	*c.c.
Sodium hydroxide	40 per cent.	170°	*c.c.
Sodium hypochlorite	15 per cent.	140°	*c.c.
Sodium thiosulphate	saturated	180°	*
Stannic chloride	saturated	180°	*
Sulphur dioxide	100 per cent.	100°	0
Sulphuretted hydrogen	100 per cent.	70°	*
Sulphuretted hydrogen	100 per cent.	100°	0
Sulphuric acid	10 per cent.	180°	*
Sulphuric acid	30 per cent.	160°	*
Sulphuric acid	50 per cent.	140°	*
Sulphuric acid	95 per cent.	100°	0
Sulphurous acid	saturated	140°	*
Tin plating solution		180°	*
Toluene	100 per cent.	100°	–
Transformer oil	100 per cent.	100°	0
Trichlorethylene	100 per cent.	70°	–
Urea	saturated	180°	*
Urine		70°	*
Water		100°	0
Zinc plating solution		180°	*
Zinc sulphate	saturated	180°	*

*=suitable; 0=some attack; c.c.=colour change; –=unsuitable.

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CHAPTER II

PHYSICAL PROPERTIES OF POLYVINYL CHLORIDE

THE MECHANICAL and physical properties of polyvinyl chloride are greatly influenced by temperature. It is therefore necessary to specify the test temperature in order to obtain comparable results. The figures quoted in Table III are given for general guidance; they were obtained from the trade literature of various manufacturers in Great Britain, the U.S.A., Germany, France, Italy, etc. Test specifications in practically every country differ in the details such as temperature, size of specimen, test load, etc., and the wide range shown in the tables would be much narrower if all the materials could have been tested under identical conditions.

Tensile strength

The tensile strength of P.V.C. is higher than that of most other thermoplastic materials. It varies between 5,500 and 9,000 p.s.i. and is greatly influenced by the methods of processing such as extrusion, rolling, moulding, calendering and particularly by stretching. It also depends on the molecular weight of the polymer and on the temperature. It decreases with increasing temperature. Compounded P.V.C. has a lower tensile strength than rigid P.V.C. due to the incorporation of plasticizers, lubricants and the like.

Elongation

Rigid unplasticized polyvinyl chloride has a low elongation (5–10 per cent.). Addition of plasticizers and lubricants increases elongation enormously and may bring it up to 300–400 per cent. Elongation increases with increasing temperature up to 100° C. (212° F.) and decreases rapidly thereafter.

Effect of temperature on tensile strength and elongation of rigid P.V.C. (*1*)

Any increase in temperature reduces the tensile strength of rigid P.V.C. as can be seen from Fig. II/1. The stress/rupture relationship of rigid P.V.C. over the entire practical range from (−40° C. to 160° C. or −40° F. to 320° F.) is shown in Fig. II/2.

The tensile strength/temperature relationship (ascertained by short time tensile tests) remains strictly linear up to a temperature of 80° C. (176° F.); at this temperature, however, a sudden decrease in strength

and stiffness takes place—the material will undergo a considerable amount of deformation without cracking—but will regain its original shape if subsequently heated.

Once the flow temperature of approximately 170° C. (340° F.) is

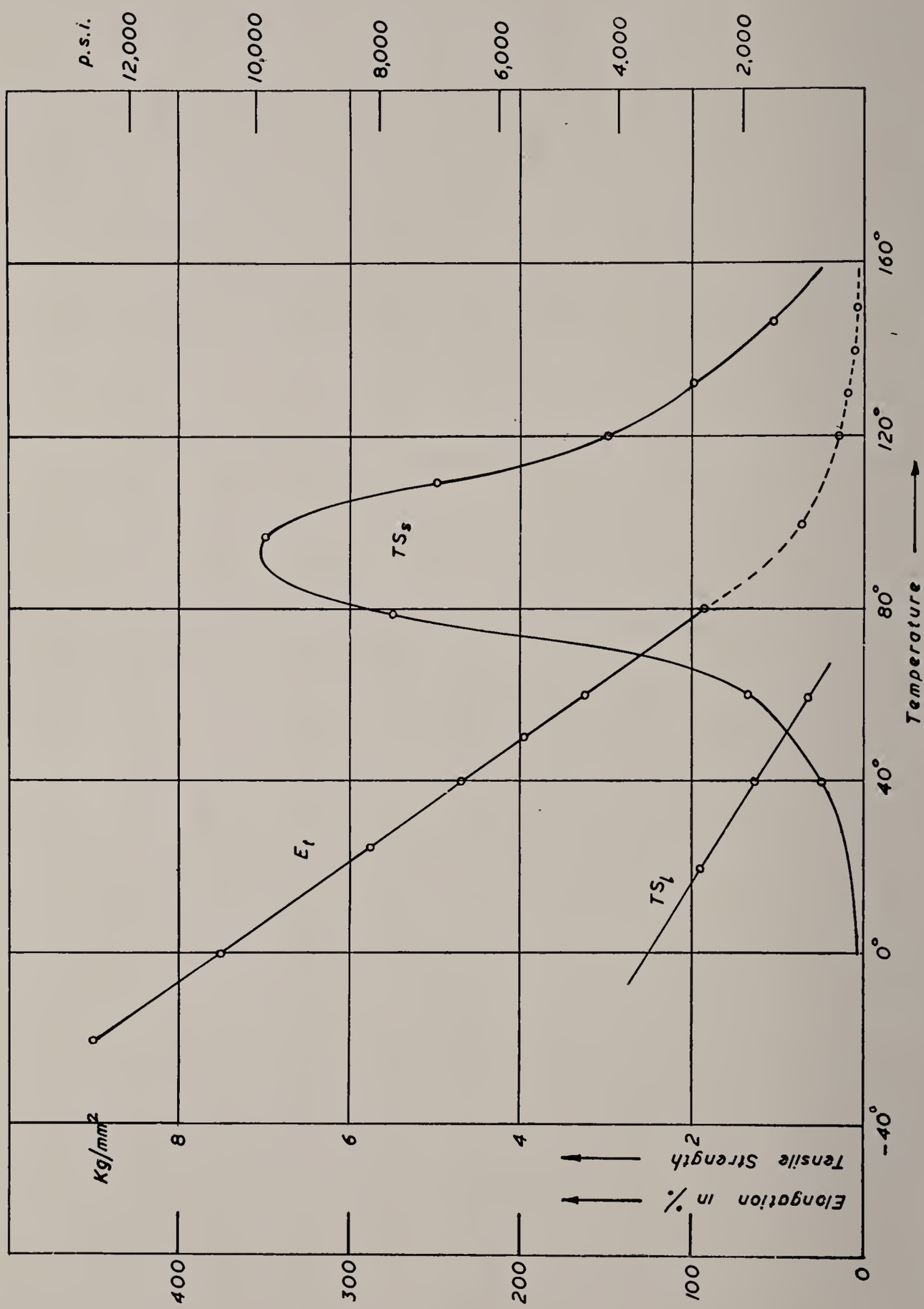

FIG. II/1.—Effect of temperature on the tensile strength and elongation of rigid P.V.C.

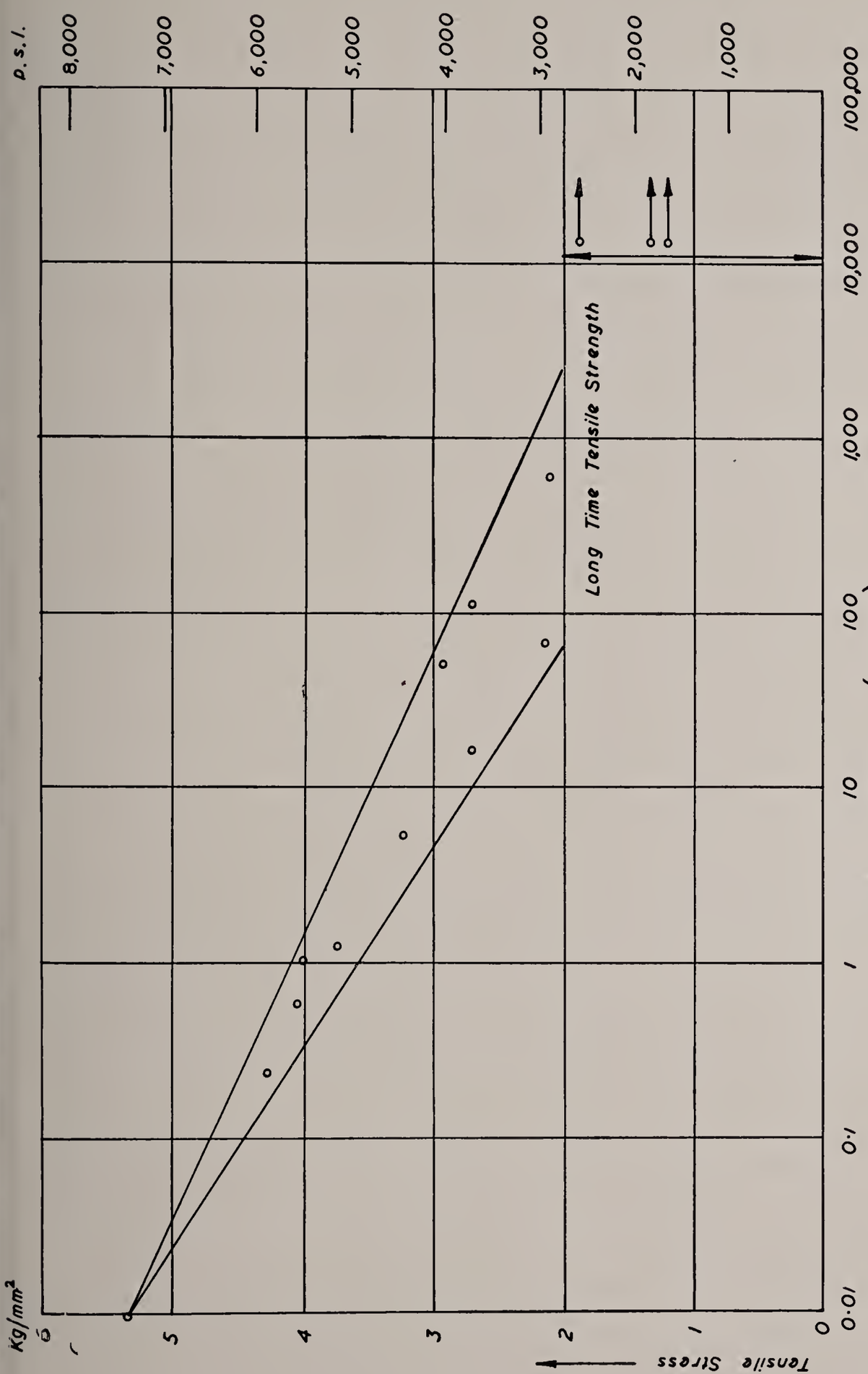

FIG. II/2.—Stress/rupture relationship of rigid P.V.C. at 20° C. (68° F.)

reached and exceeded, the material remains stable in its formed or deformed condition and does not regain its original shape.

For the purpose of designing structures in rigid P.V.C. long-time tensile strength figures have to be considered; these are considerably lower than those obtained by short-time tests—but they take into consideration deformation under continuous loading. The stress/rupture relationship of rigid P.V.C. is shown in Fig. II/2, where the applied stress is plotted against the logarithm of the corresponding rupture time at 20° C. (68° F.). The rupture stress reaches a limiting value of approximately 1,000–2,000 hours at which it can be sustained indefinitely without failure.

For the design of rigid P.V.C. constructions, a factor of safety of four should be applied to the ideal strength (continuous loading strength) for the relevant temperature.

At 20° C. (68° F.) for instance, the tensile strength of a particular brand of rigid P.V.C. was found to be 8,000 p.s.i. in a 3-minute test, whilst the corresponding figure for a long-time test was found to be 2,700 p.s.i. Computing the allowable working stress in tension from Fig. II/1 at various temperatures—and allowing a safety factor of four—the following figures are obtained.

Temperature		*Allowable working stress in tension*
° F.	° C.	p.s.i.
68	20	650
104	40	400
140	60	140

It is, therefore, unsafe to use rigid P.V.C. for structural purposes at higher temperatures and its use should be restricted to applications which do not exceed 140° F. (60° C.) unless external support is given.

The chemical resistance also suffers at elevated temperatures and it is therefore always advisable to consult the literature and appropriate 'corrosion tables' to ascertain whether P.V.C. is suitable for a particular application.

The relevant figures for the strength of rigid P.V.C. in compression or shear can be obtained by multiplying the figures ascertained for the allowable working stress in tension by 1·2 (compression) or by 0·75 (shear).

Notch sensitivity and impact strength

Rigid P.V.C. is extremely sensitive to impact, especially when notched. Izod tests show a figure of 1–5 ft. lb. Co-polymerization or compounding with other polymers improves the impact strength to a remarkable extent. The so-called high impact types of polyvinyl

chloride show an Izod figure up to 10 ft. lb. The impact strength of rigid P.V.C. decreases with decreasing temperature and becomes zero at low temperatures.

Orientation

Most of the mechanical properties of P.V.C., for instance the tensile strength, can be improved by orientation. Orientation can be brought about by stretching during calendering. A certain amount of orientation is also caused during extrusion. Calendered P.V.C. sheet or foil usually shrinks more in the direction of calendering than at right angles to it due to stretching and in cases where calendered sheet is used for lining, etc., thermal treatment is necessary to relieve stresses.

Adhesion and surface conditions

The surface of polyvinyl chloride becomes tacky on heating which is one of the reasons why polyvinyl chloride can be welded. P.V.C. sheets with glossy and shiny surfaces become less tacky on heating and are, therefore, more difficult to weld than sheets with matt surfaces.

Heat resistance

Polyvinyl chloride, like other thermoplastic materials, softens under the application of heat. The softening point of rigid polyvinyl chloride is not very pronounced and depends on a variety of factors, for instance degree of polymerization, and in the case of compounded (plasticized) P.V.C., on the type and amount of plasticizer used.

Heat conductivity

Polyvinyl chloride is a bad conductor of heat or, to put it another way, a good heat insulator. This is one of the reasons why thicker sections of P.V.C. show blisters on the surface when overheated whilst the inner part of the material is not yet plasticized. The low heat conductivity is also one of the reasons why cooling coils or heat exchangers should not be made of P.V.C. except in cases where other materials are unsuitable or where electrical insulation is required at the same time.

Gas and water vapour permeability

The gas and water vapour permeability of P.V.C. is of importance in the case of P.V.C. films and relatively thin sheets. Permeation of the gas proceeds in three stages. It dissolves at first on one side of the sheet, then diffuses through it to the other side, and finally evaporates. It is quoted as the rate of transfer of the gas across the film or sheet of unit thickness per unit area per unit pressure difference. The water vapour permeability is determined by direct measurement of the mass of water which passes through the film or sheet in a given time when

one surface is exposed to an atmosphere of given RH and the other to dry air. There are a number of variables which influence the permeation of gas and water vapours, such as temperature, plasticizer content, fillers, pressure, film thickness and molecular structure.

In general, permeability increases with increasing temperature. Plasticizers increase in most cases the rate of permeability but the effect depends on the particular type of plasticizer used and also on the temperature. Fillers such as mica and aluminium powder, i.e. fillers having a lamellar structure, cut down the permeability, whilst spherically shaped fillers have a lesser effect. The rate of gas flow decreases proportionately when the thickness of the sheet is increased.

Ageing

The effect of ageing on the mechanical properties of rigid P.V.C. was studied in Florida. It was found that the tensile strength, the flexural strength and the impact figures of ordinary types of P.V.C. gradually increased over a period of two years, and were finally approximately 3 per cent. higher than at the start. After that a slight decrease was noted. In the case of high impact P.V.C. an increase in tensile strength and flexural strength was noted up to $1\frac{1}{2}$ years of exposure. The Izod figures for high impact P.V.C. already showed a marked decrease after an exposure of four months; the decrease continued until after three years the Izod figures were 30 per cent. lower than at the beginning. The general appearance of the material did change very little during the first year, after that both types of P.V.C. became slightly yellowish and chalky.

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Table III
Physical Properties of Rigid Polyvinylchloride Materials

	Ordinary types of Rigid P.V.C	*High Impact P.V.C.*
Specific Gravity	1·38–1·72	1·32–1·35
Tensile Strength: p.s.i. at 23° C.	6,500–9,000	5,500–6,000
Elongation at break at 23° C.	3–15 per cent.	5–15 per cent.
Youngs Modulus in Bend: p.s.i.	400,000–500,000	250,000–300,000
Modulus of Elasticity in Tension: p.s.i.	400,000–500,000	250,000–300,000
Flexural Strength: p.s.i.	8,000–16,000	8,000–12,000
Compressive Strength: p.s.i.	7,500–9,500	7,000–8,000
Impact Strength (Izod, notched) ft. lb./in. of notch (B.S.1524).	2–4	8–10
Coefficient of Linear Thermal Expansion per ° C.	$6–8 \times 10^{-5}$	$10–12 \times 10^{-5}$
Thermal Conductivity: cals/cm²/sec/° C.	$3·5–3·7 \times 10^{-4}$	$4·0–4·5 \times 10^{-4}$
Specific Heat: cals/g/° C.	0·23–0·24	0·23–0·25
Heat Distortion Temperature	75°–80° C.	65°–70° C.
Flow Point	170°–180° C.	160°–170° C.
Softening Point (Vicat)	80°–100° C.	75°–78° C.
Hardness: Shore–D.	80–84	75–78
Electric Strength (short time) volts/mil	500–600	600–700
Permittivity at 1,000 cycles per second	3·0–3·2	3·5–3·8
Power Factor (tan δ) at 10^3 cycles	0·02–0·03	0·02–0·03
Volume Resistivity: Ohm cm	$3–5 \times 10^{15}$	$6–7 \times 10^{14}$
Surface Resistivity: Ohm	10^{12}–10^{13}	10^{12}–10^{13}
Flammability	Self extinguishing	Self extinguishing
Water Absorption: 24 hours at 25° C.	0·05–0·30 per cent.	0·05–0·07 per cent.
Water Vapour Permeability g/sq. m/24 hours/0·001″	5–8	2–5

CHAPTER III

MANUFACTURE OF POLYVINYL CHLORIDE

THE BASIC raw materials for the manufacture of vinyl chloride are calcium carbide (for acetylene) and hydrogen gas and chlorine gas for hydrogen chloride.

Hydrogen gas can be obtained by a variety of processes, i.e. by the so-called steam iron process, by cracking of oil, electrolysis, etc. It has to be cleaned thoroughly by washing in caustic soda. Fig. III/1 shows the hydrogen burners in a large P.V.C. plant. Chlorine, too, can be produced by electrolysis. Both gases are reacted in suitable burners when hydrogen chloride is formed; the latter is then brought into reaction with acetylene in the presence of catalysts to form vinyl chloride, a gas which liquefies at $-14°$ C.

Most factories producing polyvinyl chloride manufacture their own monomers from acetylene and hydrochloric acid in gaseous form. There are also cases where monomeric vinylchloride is shipped in tankers from one plant to another for final polymerization. Table IV shows a flow diagram of the various stages incurred during the processing of polyvinyl chloride.

Two basically different types of vinylchloride polymers are in use today—emulsion polymers and suspension polymers. In the case of emulsion polymers vinylchloride is emulsified in water, using suitable emulsifiers, such as soaps, or surface active or emulsifying agents. These also have the object of dispersing both monomers and polymers in an aqueous phase. The monomer emulsion can then be coagulated by freezing or by the addition of salts or, alternatively, it can be catalyzed in autoclaves under application of heat and pressure. The resulting polymer is then separated from the emulsion and dried. It is finally sieved according to grain size and bagged.

Vinylchloride polymers produced by the emulsion process are very fine powders; they usually contain a certain amount of residual matter (emulsifier and coagulants) and products produced from them are therefore much more sensitive to water than suspension polymers.

The emulsion process is continuous and somewhat cheaper than the suspension process. Its products are usually of high molecular weight and they are nowadays mainly used for coating, dip coating and slush-moulding.

In the case of suspension polymers the monomer, or a mixture of monomers, is dispersed in water and polymerized in the presence of

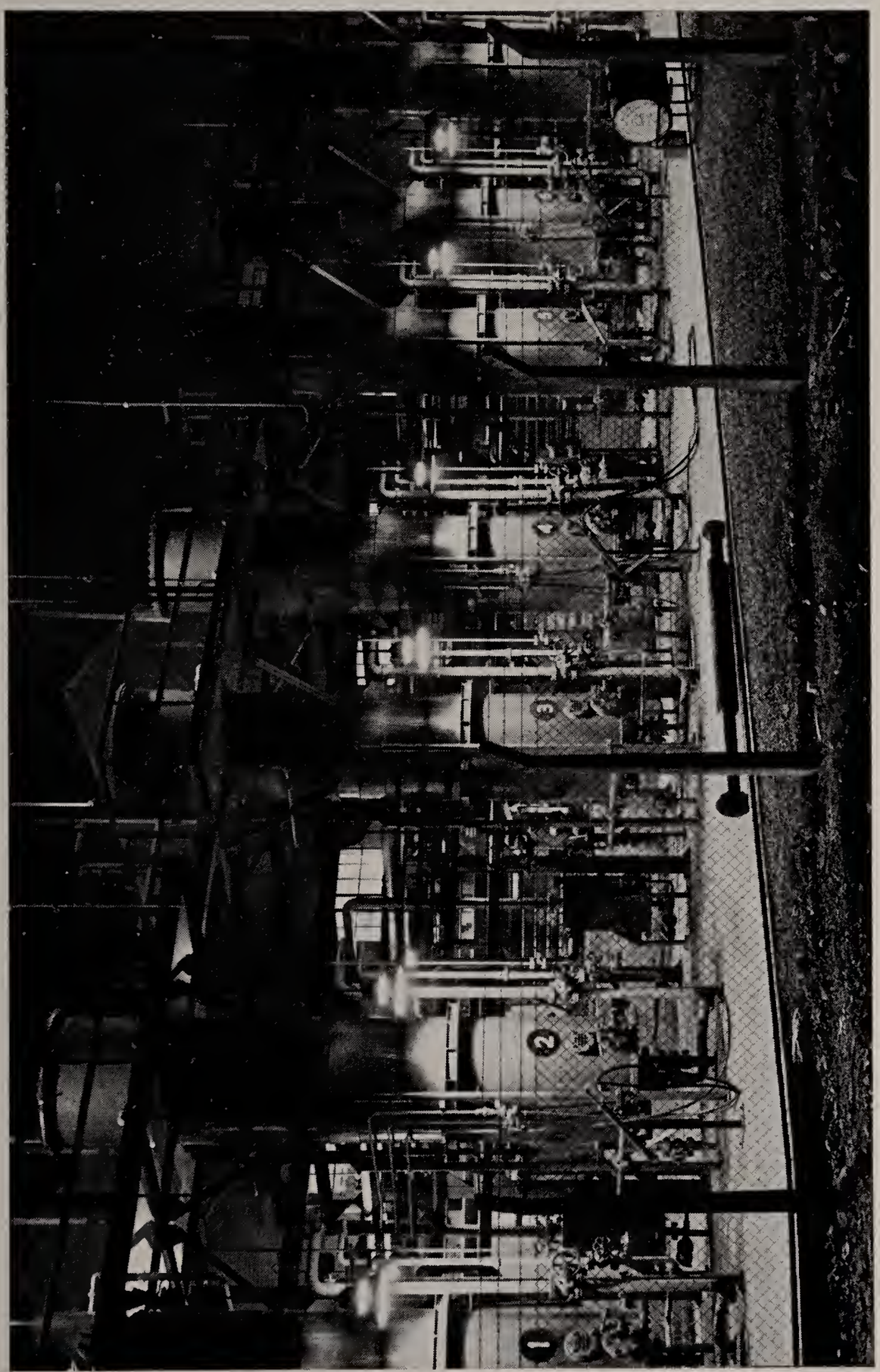

FIG. III/1.—Hydrogen chloride burners at the British Geon factory at Barry, Glamorgan.

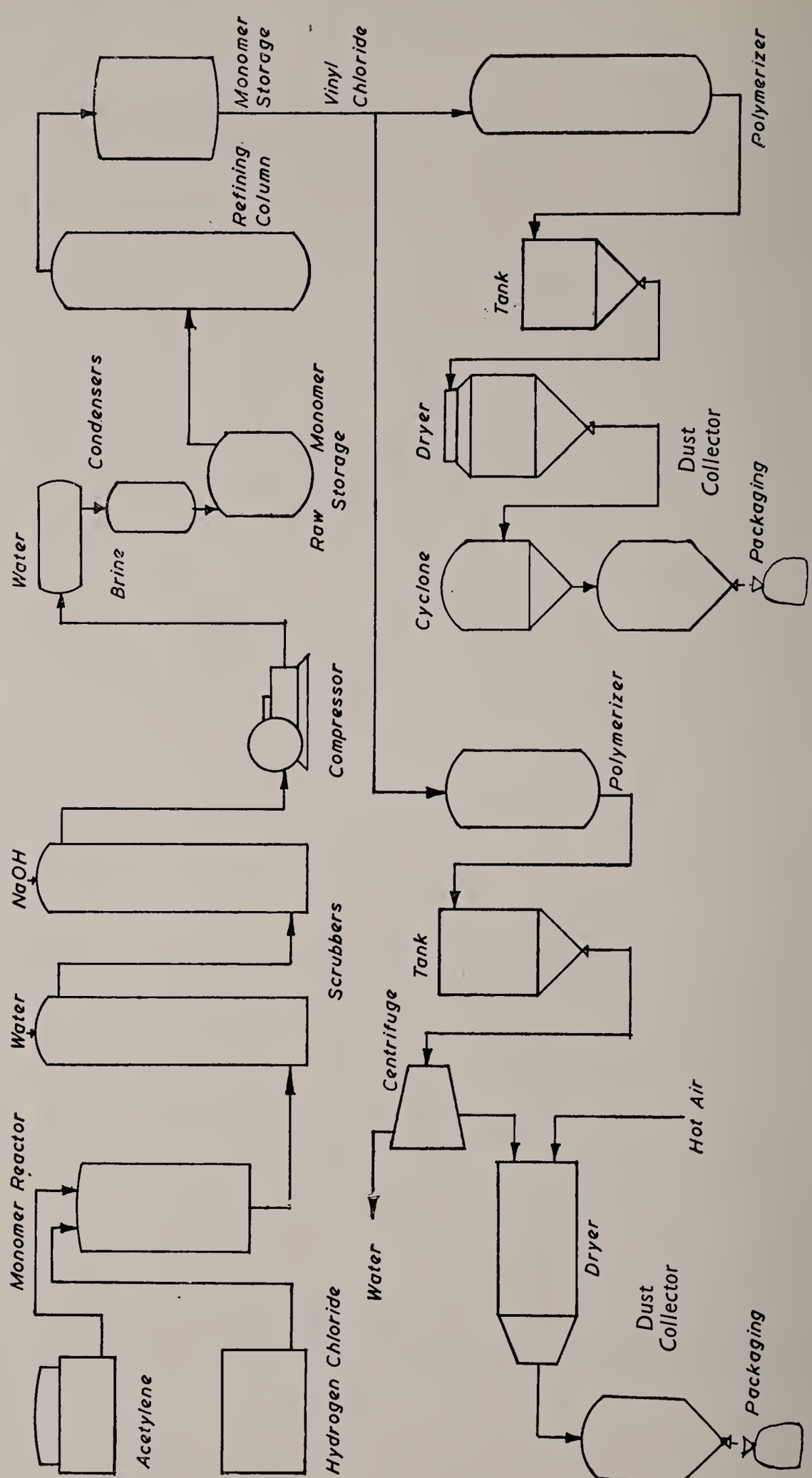

FIG. III/1a.—Flow diagram of polyvinyl chloride plant.

soluble catalysts. Vigorous mechanical stirring is applied to prevent clustering of the polymer which is obtained in the form of small globules or pearls. These are then filtered, washed, dried and bagged.

Polyvinyl chloride suspension resins are of great purity, due to the fact that very little (1 per cent. or less) suspending agent is used. The equipment used is less complex and production costs are lower than those for other processes. The suspension process has, however, several disadvantages. It is, for instance, not always easy to maintain the material in suspension during and after polymerization, and the number of different types that can be produced is somewhat limited.

The more recently built polyvinyl chloride factories in Great Britain, the United States and also in Germany employ suspension polymerization. Fig. III/2 shows the polymerizers in the reactor room of a large P.V.C. producing plant.

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Classification of Vinylchloride Polymers according to Fikentscher Values

The degree of polymerization and the molecular weight depend on the temperature at which polymerization takes place; the lower the temperature the higher the degree of polymerization.

The amount of catalyst used is likewise of great importance—the higher the amount of catalyst used the higher the degree of polymerization.

The molecular weight of vinylchloride polymers is closely related to their molecular weight and degree of polymerization; it is very often quoted in k-values.

The so-called k-value, first introduced by Fikentscher, is a measure of the degree of polymerization; it allows the assessment of the molecular weight of a polymer and it is represented by the following equation:

$$\log z = \frac{75k^2}{1 \times 1{,}5k.c} + kc$$

where c is the concentration in per cent. (i.e. g/100 mls of solution). z represents the relative viscosity of the solution at a given concentration c, and k is a constant, independent of the concentration or the viscosity of the material. It is customary to quote K which is $k \times 1000$.

To determine k the viscosity of a polyvinyl chloride solution (η_c) of a known concentration is measured first and this is followed by a measurement of the viscosity of the solvent (η_o) in the same viscometer. K can thus be determined from the Fikentscher formula as

$$z = \frac{\eta_c}{\eta_o}$$

FIG. 111/2.—General view of the polymerizers in the reactor room of British Geon Limited, Barry, Glamorgan.

The actual measurements can be carried out in a Hoeppler viscometer using a 1 per cent. solution of the polymer in cyclohexanone at 20° C.; alternatively a 2 per cent. polymer solution in hexanone can be measured in a U-type viscometer.

The molecular weight of commercial types of P.V.C. varies from 15,000–150,000, corresponding to various degrees of polymerization (250–2,500) and *K*-values of 25–85.

The lower polymers are used as raw materials for P.V.C. varnishes and lacquers (protective paints) as they dissolve in solvents quite easily; solubility decreases, however, with increasing molecular weight.

Polymers with a *K*-value of 55–70 are usually taken for the manufacture of rigid, unplasticized sheets and pipes, whilst polymers with *K*-values exceeding 80 are employed for the manufacture of pastes, etc., containing a high percentage of plasticizers.

Copolymers

Copolymerization of vinylchloride with vinylacetate, vinylidene chloride, acrylic esters, maleic esters, etc., yields copolymers with valuable properties. These copolymers are easier to process than straight polyvinyl chloride—on the other hand their resistance to some chemicals and also their softening point (or range) is in some cases slightly lower than that of straight P.V.C.

The oldest and best known copolymers in this field are those containing vinylacetate. They were first discovered by Reid of the Carbide and Carbon Chemicals Corpn., and they are marketed under the trade name Vinylite in the U.S.A., Great Britain, France, Germany, etc. Vinnol H.40 is of similar composition.

The range of Vinylite resins is quite extensive and the more important types are quoted below.

Vinylite Resins

Type	*Vinyl acetate content*	*Molecular weight*	*Used for*
VYLF	12–15 per cent.	5·000	Lacquers
VYHH	12–15 per cent.	10·000	Coatings
VYNS	10–12 per cent.	18·000	Rigid Sheets
VYNW	5–7 per cent.	25·000	Elastomers

Also of growing importance are vinyl chloride-vinylidene copolymers first developed by B. F. Goodrich under the trade name Geon. It should, however, be mentioned that some Geon types are straight vinyl chloride polymers.

Geon resins of the 100 series are straight P.V.C. Resins of the 200

series contain varying amounts of vinylidene chloride (202 contains 6 per cent.). The 400 series contains vinyl acetate.

Other vinyl copolymers of importance are Astralon (a vinyl chloride methylacrylate copolymer) and Decelith of similar composition. Both are transparent and weldable like rigid P.V.C.

Vinyl chloride-acrylonitrile copolymers are used in the form of fibres and filaments under the trade name Vinyon N and Dynel.

High impact polyvinyl chloride

The ordinary types of rigid, unplasticized P.V.C. are very sensitive to impact and it has always been felt that this shortcoming restricts the widespread use of rigid P.V.C. for plant applications. New, modified P.V.C. types, first suggested by Jennings (*1*) opened up new fields of applications.

The so-called high impact P.V.C. can, for instance, be used in the manufacture of pipes which can be threaded like steel pipes.

Some of the high impact types of rigid P.V.C. contain Buna N, others are modified with a styrene-acrylonitrile copolymer.

These high impact types have superior impact strength but their chemical resistance is weakened by the modifying compounds which are merely present in the form of discreet dispersions in the polyvinyl chloride. The chemical resistance of sheets, pipes, rods, etc., made from high impact P.V.C. is in general not much better than the resistance of the modifying compound. A typical example is resistance to chlorine gas. Ordinary rigid P.V.C. will stand up to it quite satisfactorily—whilst high impact P.V.C. becomes porous due to the fact that the modifier becomes decomposed and perishes.

Compounding of P.V.C.

Premixing is carried out in conventional mixing equipment (dough mixers, ribbon blenders, tumblers, etc.). The dry components—the resin, stabilizers, fillers and pigments—are charged into the mixer and thoroughly blended. Plasticizers are then added and the mixing continued until a homogenous mix is achieved. Fig. III/3 shows compounding of P.V.C. The premix is then transferred to a Banbury Mill or to an extruder and processed under heat and finally granulated or pelletized and bagged.

Processing of P.V.C.

Calendering. Films, foil and sheet are produced on calenders. The hot premix is taken from the Banbury and transferred to the calender which consists of a multitude of rollers heated to temperatures varying from 310–370° F. Passing through and over these rollers, films and sheets varying in thickness from 0·002 in. to 0·025 in. can be obtained by repeated calendering or on a Rotocure machine.

Extrusion. Granulated and pelletized compounds can be fed into an

FIG. III/3.—Compounding polyvinyl chloride with plasticizers, stabilizers, etc. The compound is seen leaving the rollers from which it passes to a cooling bath before being cut into fillets.

extruder with single or multiple screws. The barrel and the die system of the extruder are heated to temperatures varying from 340° to 380° F. whilst the screw is sometimes water-cooled. The material is thoroughly masticated and plasticized through the action of the screw and then formed into pipes or profiled sections by the die system.

Fig. III/4 shows an extruding plant with haul-off gear for the production of rigid P.V.C. pipes.

Moulding. P.V.C. compound can be moulded into shapes by a variety of processes—such as compression moulding, transfer moulding and, more recently, also by injection moulding.

Dispersions. P.V.C. resins can be dispersed in plasticizers and other ingredients to form fluid compounds—dispersions. Dispersions can be classified as plastisols—i.e. dispersions which do not contain volatile matter but sufficient liquid plasticizers to remain fluid after mixing—and organosols—which are more liquid than plastisols and contain volatile organic solvents in addition to plasticizers.

Plastisols are used for the casting of free and supported films of substantial thickness and for protective coatings produced by dipping or spraying—organosols for casting of free and supported films of less than 0·002 in. thickness.

Slush moulding. P.V.C. plastisols can be filled into metal moulds which are subsequently closed and subjected to heat (350°–400° F.) to gel the plastisol. The finished article can be stripped quite easily from the moulds after cooling.

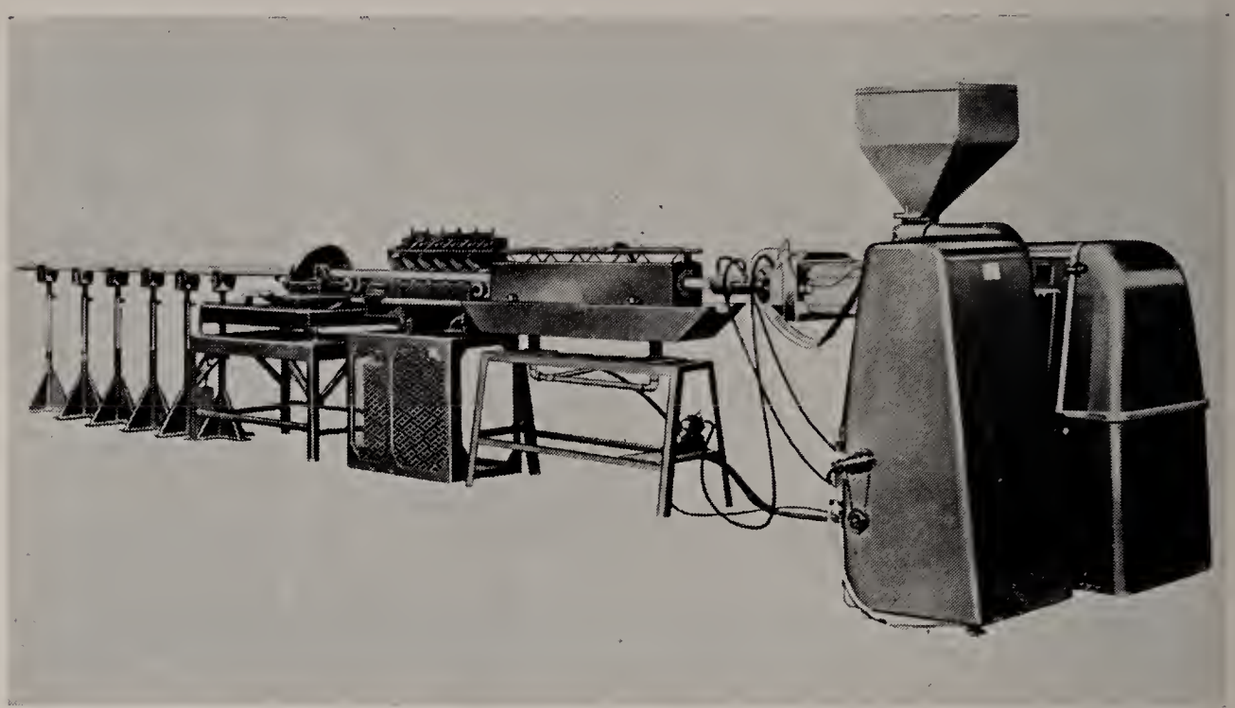

FIG. III/4.—Extruding plant and haul-off gear for the production of rigid polyvinyl chloride pipes.

Commercial aspects

Polyvinyl chloride accounts for a very large proportion of the world's production of thermoplastic materials. Official production figures for 1957 are not yet available but estimates indicate that more than a million tons of P.V.C. were produced during that year.

The approximate tonnages produced in various countries are quoted below (from O.E.E.C.):

Australia	6,000
Austria	8,000
Belgium	15,000
Canada	25,000
France	52,000
Germany (Western)	96,000
Germany (Eastern)	75,000
Great Britain	67,000
Italy	48,000
Jugoslavia	10,000
Norway	2,000
Sweden	7,000
U.S.A.	350,000
	851,000 tons

Figures for the U.S.S.R., Poland, Hungary and Roumania could not be obtained, but it is estimated that the P.V.C. production of these countries considerably exceeds 100,000 tons. The Japanese P.V.C. production amounts to approximately 120,000 tons per annum. An interesting consumer analysis was recently given in *Modern Plastics*. According to this the following sectors of the American industry contributed to the sales of P.V.C. in the following percentages (1958).

Film and Sheeting	23·0 per cent.
Fabric coating	8·0 per cent.
Flooring	18·0 per cent.
Moulding and extrusion	31·0 per cent.
Miscellaneous	15·0 per cent.
Export	5·0 per cent.

Comparable figures are, unfortunately, not available for other parts of the world.

Manufacturers of Vinyl Chloride Polymers

AUSTRALIA

I.C.I. (Australia & New Zealand) Ltd., Botany Bay, New South Wales.

ASIA

Japan

Asahi Dow Co. Ltd., Nobeoka, Miyazaki Pref.
Danki Kagaku Kogyo K.K., Shibukawa, Gunma Pref.
Japanese Geon Co. Ltd., Kambara, Shizuoka Pref.
Kanegafuchi Chemical Industry Co. Ltd., Torikai, Osaka Pref.
Kurashiki Rayon Co. Ltd., Kurashiki City.
Kurashiki Rayon Co. Ltd., Toyama City.
Kureha Chemical Industry Co. Ltd., Nishiki, Kukushima Pref.
Mitsui Chemical Industry Co. Ltd., Nagoya City.
Monsanto-Kasei Chemical Co., Yokkaichi City.
Nippon Carbide Industries Co. Inc., Uozu, Toyama-Pref.
Nippon Synthetic Chemical Industry Co. Ltd., Ogaki, Gifu Pref.
Shin Nippon Chisso Hiryo K.K., Minomata, Kumamoto-Pref.
Showa Synthetic Chemical Industry Co. Ltd., Kanose, Niigata-Pref.
Sumitomo Chemical Co. Ltd., Kikumoto, Niihama City.
Tekkosha Co. Ltd., Sakata, Yamagata-Pref.
Toa Gosei Chemical Industry Co. Ltd., Nagoya City.

AMERICA

Brazil

Geon do Brasil, S.A., Sao Paulo.

Canada

Canadian Resins and Chemicals, Shawinigan Falls, Quebec.
B. F. Goodrich, Canada Ltd., Kitchener, Ontario.
Monsanto Canada Ltd., Montreal, Quebec.

MEXICO	Geon do Mexico, S.A., Mexico City.
	Monsanto Mexicana S.A., Lecheria.
U.S.A.	Atlantic Tubing and Rubber, Cranston, R.I.
	Bakelite Corp., Div. of Union Carbide Corp., Texas City, Texas.
	Bakelite Corp., Div. of Union Carbide Corp., Charleston, W. Va.
	The Borden Co., Polyco Dept., Peabody, Mass.
	Cary Chemicals Inc., Flemington, N.J.
	Diamond Alkali Co., Pasadena, Texas.
	Dow Chemical Co., Midland Div., Midland, Mich.
	Eleonora Chemical Corp., Passaic, N.J.
	Escambia Chemical Corp., Pensacola, Fla.
	Firestone Tire and Rubber Co., Pottstown, Pa.
	General Tire and Rubber Co., Ashtabula, Ohio.
	B. F. Goodrich Chemical Co., Niagara Falls, N.Y.
	B. F. Goodrich Chemical Co., Avon Lake, Ohio.
	Goodyear Tire & Rubber Co., Akron, Ohio.
	Great American Plastics, Leominster, Mass.
	Insular Chemical Corp., Hicksville, Long Island, N.Y.
	Monsanto Chemical Co., Springfield, Mass.
	Polymer Corp., Los Angeles, Calif.
	Thompson Chemical Co., Hebronville, Mass.
	United States Rubber Co., Naugatuck Chemical Div., Painesville, Ohio.
EUROPE	
AUSTRIA	Solvic, A. G., Hallein.
BELGIUM	Solvic S.A. pour l'Industrie des Matières Plastiques, Brussels.
FRANCE	Kuhlmann, Brignoux, Isère.
	Pechiney, St. Auban de Roussilon.
	Rhône Poulenc, Peage de Roussillon, Isère.
	Rhône Poulenc, St. Fons, Rhône.
	St. Gobain, Montlucon, Allier.
	Solvic, Tavaux, Jura.
	St. Gobain, St. Fons, Rhône.
GERMANY (Western part only)	Badische Anilin and Soda Fabrik, A.G., Ludwigshafen/Rhein.
	Chemische Werke Hüls GmbH, Marl.
	Farbwerke Hoechst, Frankfurt/Main.
	Wacker-Chemie, München.
GREAT BRITAIN	Bakelite Limited, Aycliffe.
	British Geon Limited, Barry.
	Imperial Chemical Industries, Hillhouse.
HOLLAND	N.V. Bataafse Petroleum Maatschappij, Pernis.
ITALY	A.C.N.A., Cesare Maderno.
	Montecatini, Milan.
	Sicedison, S.p.A., Porte Marghera.
	Solvic.
JUGOSLAVIA	Jugovinil, Belgrade.
NORWAY	Norsk Hydro.
SPAIN	Etino-Quimica S.A., Barcelona.
	Solvic.
SWEDEN	Stockholms Superfosfat Fabriks A.B., Stockholm.
SWITZERLAND	Usines Électriques et Chimiques, S.A., Lonza.

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CHAPTER IV

COMMERCIAL FORMS OF POLYVINYL CHLORIDE

Standard Semi-Finished Products

Foil and sheet

Rigid, unplasticized P.V.C. foil can be obtained in the form of rolls up to 48 in. wide. These foils are produced by calendering and this manufacturing process limits their thickness which can be varied from 0·002 in. to approximately 0·040 in. Calendered foils are not always free from pinholes and careful testing by means of a spark tester is recommended in cases where such foil is used for the lining of tanks. Some firms supply a special 'lining grade' and guarantee freedom from pinholes.

'Luvitherm' is another special grade of unplasticized P.V.C. foil mainly used for electrical purposes and in packaging. It has greater mechanical strength than the ordinary P.V.C. foil due to a stretching process applied during calendering. This results in orientation of the foil.

Calendered foils can be laminated under simultaneous application of heat and pressure in multi-daylight presses. Sheets so produced vary in thickness from $\frac{1}{16}$ in. to 1 in. and they are made in standard sizes. (In Great Britain 6 ft. × 3 ft. or 8 ft. × 4 ft.). Some firms are able to offer larger sheets, for instance 12 ft. × 10 ft. These are useful for the lining of large tanks, but they are difficult to handle in a fabrication shop.

One American firm produces rigid P.V.C. sheets on a Rotocure machine and offers to cut these sheets to any reasonable length. These rotocured sheets are 4 ft. wide and they are available in $\frac{1}{16}$ in., $\frac{1}{8}$ in., $\frac{3}{16}$ in. and $\frac{1}{4}$ in. thickness.

Thicker sheets (1 in. and heavier) are compression moulded from P.V.C. powders or granules in the same way as blocks.

Thermal treatment and tests

P.V.C. sheets used for the fabrication of chemical plant should be heat treated (preshrunk) to relieve stresses from the preceding calendering operation. These stresses are not relieved during lamination as the sheets are firmly locked between the platens of the press.

Most sheet manufacturers temper their sheets for 24 hours in special heating chambers at temperatures varying from 260° to 285° F. (130°–140° C.).

Insufficient heat treatment causes the sheets to undergo a further shrinking process when they are heated before being formed into tubes or when they are used for the lining of tanks.

P.V.C. sheets should be covered on both sides with paper to prevent scratching during transport or storage; this also facilitates marking out with pencils. The paper covering can be removed after cutting.

A delamination test is often carried out to check whether the sheets have been properly laminated. This test is standard practice in America and involves immersion of a test specimen in acetone for 2 hours. Specimens are usually cut from the edges of the sheets to be tested. Sheets showing delamination under these conditions are rejected.

Surface finish

Rigid P.V.C. sheets are available in a variety of finishes: matt, satin finish and glossy. A matt finish is preferred for operations involving welding or cementing.

Pigmentation

Most P.V.C. sheets are supplied in colours. Unpigmented sheets should be semi-translucent and slightly yellow. It is, however, difficult to maintain a specific colour and this is one of the reasons why dyes or pigments are added. These should be stable to light and chemicals and should not be affected by heating to the temperatures required by welding or heat forming.

Each manufacturer has his own colour scheme which helps the user to identify sheets of different makes.

Laminated P.V.C. sheet

Plasticized P.V.C. sheets can be laminated with rigid P.V.C. sheets to form a 'sandwich'. These laminated sheets are less liable to fracture on impact than ordinary rigid P.V.C. sheets. They are often used for the lining of tanks and for duct work.

The plasticized part of the laminated sheet can be cemented to steel quite easily—whilst the unplasticized side facing the liquid in the tank has the full chemical resistance of unplasticized P.V.C.

Expanded metals can also be sandwiched between two layers of plasticized or unplasticized P.V.C.; such laminates have improved mechanical properties—they can also be used for the fabrication of self-supporting tanks which are intended for work at elevated temperatures. Expansion or contraction of the P.V.C. sheets is greatly reduced as the metal embedded opposes the movement of the surrounding P.V.C.

Plasticized P.V.C. sheet

Thin plasticized P.V.C. sheets are produced by calendering, thicker

sheets by lamination on a multi-daylight press or by rotocuring. These sheets can be supplied in a variety of qualities, mainly differing in plasticizer content and hardness, to match other materials such as leather and rubber. The following materials can be matched as far as hardness is concerned.

Leather	60–80° Shore "A"
Rubber, general commercial quality	60–80° Shore "A"
Soft rubber	45–60° Shore "A"

Plasticized P.V.C., especially the softer grades, are highly suitable for packings and gaskets for pipe lines and duct lines. Saechtling discussed P.V.C. gaskets and other types of gaskets made from chemically resistant rubbers. Plasticized P.V.C. gaskets and packings can be used for applications involving temperatures from 32° F. (0° C.) to 105° F. (40° C.). Special types are available for work at even lower temperatures. Plasticized P.V.C. has a very good 'nerve' over a wide range of temperatures, but for applications involving pressure 40° C. should not be exceeded.

The most important applications for plasticized P.V.C. sheet are tank linings (see Chapter XIII).

Blocks

P.V.C. blocks in limited sizes (20 in. × 20 in.) and thicknesses up to 6 in. are made by compression moulding.

Pipes and tubes

Rigid P.V.C. pipes and tubes became first available in 1937. A great deal has since been learned about plumbing in P.V.C. and first class installations can now be made with little risk of failures.

The earlier pipes were extruded in Germany using ram extruders; insufficient plastification on these machines yielded pipes with rough surfaces, and wide variations in bore and wall thickness.

Modern screw extruders achieve the production of better pipes with closely controlled dimensions. Extruded P.V.C. pipes up to 14 in. bore are regular stock items, larger bore pipes (up to 18 in.) are manufactured against orders.

Some countries have now standards for P.V.C. pipes and tubing and readers are referred to the list of standards contained in the appendix.

Plasticized tubing (clear or pigmented) is produced in a great variety of sizes up to 3 in. bore. Special specifications are in force in many countries for the supply and use of non-toxic P.V.C. tubing to be used for food processing industries.

Pre-stressed P.V.C. tubing

Most thermoplastic materials have a 'memory', i.e. they can be

deformed under heat and pressure but they will try to regain their original shape when the pressure (or stress) is relieved by subsequent application of heat and cooling.

Use of this phenomenon is made in the so-called 'Kautex-Vietum' process for coating articles with an impervious, corrosion resistant surface of unplasticized P.V.C. Coating is achieved by using pre-expanded P.V.C. tubing which can be drawn over the article to be coated. Subsequent heat treatment in an oven or by blowing hot air over its surface causes the tubing to shrink and to fit snugly to the article.

For the lining of the inner walls of a metal tube pre-shrunk P.V.C. tubing is employed. Subsequent heat treatment causes the material to expand and to adhere to the inside of the metal tube.

The 'Vietum' process is simple and effective; it is patented in many countries. (B.P. 709,370 & 719,604.)

Rods

P.V.C. rods varying from filler rods ($\frac{1}{16}$ in. thick) to solid rods of 4 in. diameter are produced by continuous extrusion. Few firms are able to produce sound rods in diameters larger than 3 in. and some of them add a small amount of plasticizer to the compound to improve extrusion. Rods exceeding 4 in. in diameter are definitely plasticized.

The extrusion of thicker P.V.C. rods presents certain technical problems; some manufacturers produce, therefore, hollow rods (with a bore of approximately 1 in.). These are quite suitable for the machining of parts, for instance valve parts, and they are cheaper than solid rods due to the saving in raw material.

Non-Standard Products

Rigid, semi-rigid and plasticized P.V.C. extrusions and mouldings are produced by specialized firms in many countries. Mass production of these parts results in competitive prices and fabricators and welders are well advised to make use of such extrusions and mouldings instead of cutting parts from sheet or block.

Flanges and fittings can be compression moulded from unplasticized P.V.C. compounds; powders or granules are pressed into small blocks or cylinders which are then pre-heated (plasticized) in special heating chambers or in a dielectric heater and then transferred to the moulding press. Moulds for this process are relatively simple and inexpensive—compression moulding of rigid P.V.C. parts is therefore an economical proposition even in small numbers. Some firms use rigid P.V.C. scrap for compression moulding and mouldings so produced can be recognized by their mottled appearance; they are inferior to mouldings produced from virgin material.

Injection moulding of rigid P.V.C. is only advisable for mass production as moulds are expensive and the costs for injection moulding machines are many times higher than those for compression moulding machines.

Typical examples of injection moulded parts in rigid P.V.C. are fittings for pipes, valves and impellers for pumps.

Inexpensive mouldings in plasticized P.V.C. can be produced by dipping or injection moulding.

P.V.C. coatings and paints

P.V.C. coatings and paints can be applied by spraying or brushing. Several coats are usually applied; the articles are then transferred to an oven and baked for a certain specified time to drive off solvents and some of the plasticizer. Hot spraying of plasticized compounds, using special spraying equipment, seems to find widespread applications in the U.S.A. It has the advantage that the subsequent baking of the coated articles can be eliminated.

Plastisol coatings

Plastisols can be used to protect steel structures and metal fabrications. Large objects such as duct sections, fan housings and rotors, tanks and the like, are preheated in a suitable oven to bring them to a temperature of approximately 320° F. (160° C.). They are then withdrawn from the oven and carefully immersed into a tank containing plastisols where they are left for a short time after which they are withdrawn and left to cool. They are then ready for use. The length of the immersion period depends on various factors, for instance, the desired thickness of the coating, and has to be established by experiments.

Plastisol coatings are an excellent means of protection and may become a serious competitor to rigid P.V.C. fabrications. Initial costs of the equipment are high—but the costs per square foot of coating are low—about one third of that of rigid P.V.C. fabrications. The final costs, after adding the costs of the steel fabrications to those for the actual coating, are approximately 50 per cent. lower than those of rigid P.V.C. fabrications.

Polyvinyl Chloride Fibres and Textiles

Filtercloth and textiles made from polyvinyl chloride filaments or yarns became first known in 1936. Polyvinyl chloride does not dissolve easily in cheap solvents and the earlier filaments had to be spun from post-chlorinated P.V.C. solutions (PC); the resulting textiles were known as PC fibres, PC filaments and PC filter cloth.

PC filtercloth excels by outstanding durability and it became, within a short time, famous for its properties. French research workers of the

Rhodiaceta concern investigated certain spinning problems during the last war; they found that P.V.C. could be dissolved quite easily in solutions containing carbon-disulphide and acetone; they also found that these solutions could be spun without difficulties.

No use was made of this discovery during the German occupation of France but, shortly after the war, large scale production of P.V.C. fibres and filaments was started by Rhodiaceta at Lyons. The production programme comprises the following:—

Rhovyl—continuous filaments.
Fibravyl—staple fibre
Thermovyl—staple fibre (heat treated).
Isovyl—fibres with relatively large diameter.

Both Rhovyl and Thermovyl textiles can be pre-shrunk in boiling soda solution; this treatment is of particular importance for filtercloth to be used for the filtration of very hot liquids. Pre-shrunk filtercloth is not prone to further shrinkage in use and therefore gives better results than untreated cloth.

PC textiles have by now practically disappeared from the market and P.V.C. textiles have taken their place. Some of the newer textiles such as Terylene, Nylon, Orlon and the like are, however, cheaper in production than P.V.C. textiles resulting in fierce competition in this field.

Other industrial applications for P.V.C. textiles are protective clothing and non-inflammable curtains, furnishings and the like for aircraft and ships.

P.V.C. bristles are used for brushes which may come into contact with acids and concentrated alkalies.

'Paper'

Polyvinyl chloride staple fibres can be sintered together by special processes, when sheet-like materials are obtained which greatly resemble ordinary filter paper.

Scrap

The scrap of most thermoplastic materials has a certain value which in some cases amounts to approximately 50 per cent. of the value of the virgin material.

Unplasticized P.V.C. scrap is at the present time of no commercial value in most countries, and it would appear that the solution of this problem would be of commercial importance.

Unplasticized P.V.C. scrap is reclaimed in Germany where it is bought up by manufacturers of flooring materials for approximately 4d. per lb. Swarf from turning operations has been used in Eastern Germany for the filling of mattresses and upholstery and here and there also to protect strawberry plants from slugs. It is reported that P.V.C. swarf placed around these plants prevents slugs from reaching the fruit.

TABLE IV

TRADE NAMES OF P.V.C. COMPOUNDS AND PRODUCTS

	Granules or Powder	*Rigid P.V.C.*	*Plasticized P.V.C.*	*Coatings etc.*	*Manufactured by*
Afcodur		*			Soc. Péchiney, France.
Afcovyl	*				Soc. Péchiney, France.
Agilide		*			American Agile Coropration, U.S.A.
Amerplate			*	*	Amercoat Corporation, U.S.A.
Ampcoflex		*			Atlas Mineral Products Co., U.S.A.
Astralon, C.P.		*			Dynamit A.G., Germany.
Benvic	*				Solvic S.A., Belgium and France.
Boltaron		*	*		Bolta, U.S.A.
Breon	*				British Geon Ltd., Great Britain.
Chemidus		*			Chemidus Plastics Ltd., Great Britain.
Cobex		*			B.X. Plastics Ltd., Great Britain.
Corvic	*				Imperial Chemical Industries Ltd., G.B.
Covichoc		*	*		Lacollonge-Flexone: France & Belgium.
Covidur		*			Lacollonge-Flexone: France & Belgium.
Covileum			*		Lacollonge-Flexone: France & Belgium.
Covinite			*		Lacollonge-Flexone: France & Belgium.
Covired			*		Lacollonge-Flexone: France & Belgium.
Darvic		*			Imperial Chemical Industries Ltd., G.B.
Decelith, C.P.		*			VEB Eilenburger Celluloidwerk, Germany.
Durajoint			*		Micanite & Insulators Ltd., G.B.
Duraseal			*		Micanite & Insulators Ltd., G.B.
Durastrip			*		Micanite & Insulators Ltd., G.B.
Dynadur		*			Dynarohrwerk G.m.b.H. (Germany), Germany.
Dytrodur		*			Engel A.G., Switzerland.
Ekadur		*			VEB Kombinat Bitterfeld, Germany.
Ekalit			*		VEB Kombinat Bitterfeld, Germany.
Ekalon		*	*		VEB Kombinat Bitterfeld, Germany.
Ekavyl	*				Ets. Kuhlmann, France.
Exon	*				Firestone Plastics Co., U.S.A.
Fibravyl				F	Rhodiaceta, France & Germany.
Geberit		*			Gebert & Cie., Switzerland.
Genalon		*			Anorgana, Germany.
Genotherm		*			Anorgana, Germany.
Geon	*				B. F. Goodrich Chemical Co., U.S.; British Geon Ltd., G.B.
Gobinyle	*				Soc. St. Gobain, France.
Gutan			*		H. Rost & Co., Germany.
Guttasyn			*		H. Rost & Co., Germany.
Hostalit (C.P.)		*	*		Farbwerke Hoechst, Germany.
Igelit	*	*	*		formerly produced by BASF, Germany.
Isovyl				F	Rhodiaceta, France & Germany.
Kanevinyl	*				Kanegafuchi Chemical Ind. Ltd., Germany.
Kawekan			*		VEB Kabelwerk Koepenick, Germany.
Koroseal			*		B. F. Goodrich Co., U.S.A.
Lucoflex		*			Soc. St. Gobain, France.
Lucolene	*				Soc. St. Gobain, France.
Luvitherm		*			BASF, Germany.
Marvinol	*				Naugatuck Chemical Co., U.S.A.
Mavinil		*			Karl Troxler A.G., Switzerland.
Mipolam			*		Dynamit, A.G., Germany.

C.P. = Copolymer; F. = Fibres or filaments.

	Granules or Powder	*Rigid P.V.C.*	*Plasticized P.V.C.*	*Coatings etc.*	*Manufactured by*
Nicodur		*			Rhein-Plastic Rohr, G.m.b.H., Germany.
Oxythene		*		*	Horwitch-Smith & Co. Ltd., Gt. Britain.
Pee-Vee-Cee		*			Atlas Mineral Products Co., U.S.A.
Pegulan			*		Pfaelzische Gummiwerke, Germany.
Pliovic	*				Goodyear Tire & Rubber Co., U.S.A.
Policor		*			Polva Netherland N.V., Holland.
Polisanite		*			Polva Netherland N.V., Holland.
Polivolt		*			Polva Netherland N.V., Holland.
Polyorc		*			Yorkshire Imperial Metals Ltd., Great Britain.
Quelflex			*		Quelcor, Inc., U.S.A.
Quexon		*			Quelcor, Inc., U.S.A.
Rhenadur		*			Rheinische Gummi & Celluloidwarenfabrik, Germany.
Rhenalon (C.P.)		*			Rheinische Gummi & Celluloidwarenfabrik, Germany.
Rhovyl				F	Rhodiaceta, France & Germany.
Rigiflex		*	*		Quelcor, Inc., U.S.A.
Rilene		*			Rubber Improvement Ltd., G.B.
Rilfoil			*		Rubber Improvement Ltd., G.B.
Rilotank			*		Rubber Improvement Ltd., G.B.
Rilprint		*			Rubber Improvement Ltd., G.B.
Seilon		*			Seiberling Rubber Co., U.S.A.
Sicodur		*			Mazuchelli Celluloide S.P.A., Italy.
Sicoprint		*			Mazuchelli Celluloide S.P.A., Italy.
Sicovinyl		*			Mazuchelli Celluloide S.P.A., Italy.
Sintilon		*			Imperial Chemical Industries Ltd., G.B.
Solvic		*			Solvic S.A., Belgium & France.
Somoplas		*			Société pour les Metaux Ouvrés, Sw.
Sumit		*	*		Schrupp & Co., Germany.
Supradur		*			Suedwestchemie, Germany.
Symadur		*			Symalit A.G., Switzerland.
Thermovyl				F	Rhodiaceta, France & Germany.
Trovidur		*			Dynamit A.G., Germany.
Tygon			*	*	U.S. Stoneware Company, U.S.A.
Ultron			*		Monsanto Chemical Co., U.S.A.
Van-Cor		*			Van Dorn Iron Works Co., U.S.A.
Velbex			*		B.X. Plastics, Great Britain.
Velon			*		Firestone Plastics Co., U.S.A.
Vestolit	*				Chemische Werke Hüls, Germany.
Vietum			*		Kautex, Germany, Lacrinoid, G.B.
Vinatex		*	*	*	Vinatex Ltd.
Vinidur		*			BASF, Germany.
Vinnol	*	*	*		Dr. Alexander Wacker, Germany.
Vinylaz	*				Soc. Belge de l'Azote, Belgium.
Vinylite	*				Union Carbide, U.S.A.
Vipla	*				Montecatini S.A., Italy.
Viplast	*				Montecatini, S.A., Italy.
Vitrone		*	*		Stanley-Smith & Co. Ltd., Great Britain.
Vybak		*	*		Bakelite Ltd., Great Britain.
Vyflex			*		Kaykor Industries Inc., U.S.A.
Vykem		*			British Moulded Products Ltd., Gt. Britain.
Welvic			*		Imperial Chemical Industries Ltd., G.B.
Zeroc			*		Atlas Mineral Products Co., U.S.A.

C.P. = Copolymer; F. = Fibres or filaments.

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CHAPTER V

CEMENTS

UNIVERSAL cements for plastic materials are not available and the choice of a particular cement for a particular purpose depends on many factors.

Ease of application, bonding without preheating, absence of toxic or highly inflammable fumes, quicker setting and higher bonding strength are of deciding influence for the selection of a cement.

The bonding properties of a cement suitable for plastic materials depend upon physical and chemical factors.

As far as physical factors are concerned the following points have to be considered by the makers of such cements:

Porosity, Flexibility } of the surfaces to be bonded.
Surface tension
Viscosity
Wettability
Drying power
Drying time
Volatility and diffusion of the solvents
Mechanical properties of the resulting joint
(tensile strength, elasticity, elongation, peeling strength).

The chemical factors to be taken into account are:—
Polarity
Influence of monomolecular layers
Boundary reactions
Chemical reactions in general.

Most plastics have a smooth and shiny surface which makes bonding more difficult; in such cases bonding can be improved by treating the surfaces with a suitable solvent (methyl-ethyl-ketone for instance, in the case of P.V.C.).

The migration of plasticizers from the sheets to be cemented into the adhesive layer has also to be considered as this bond may eventually be destroyed by the plasticizer; this can be prevented by the proper choice of the polymers, plasticizers and solvents.

Cements based on artificial rubbers such as Neoprene, Butyl rubber, Buna rubber and the like yield excellent results. The most important

representative in this line is Neoprene, as it has the highest initial adhesive power of all artificial rubbers.

The earliest cements used for the bonding of rigid, semi-rigid and plasticized P.V.C. were developed in Germany before 1939. A wide range of cements was offered; some of the more important German cements are mentioned below for historical reasons.

The composition of German P.V.C. cements is comparatively easy to decipher, as their code indicates their composition. The first two letters (in general PC—refer to the basis of the cement—post-chlorinated P.V.C.); the numerals indicate the P.V.C. content, e.g. PC.13 is a cement containing 13 per cent. post-chlorinated P.V.C. and 87 per cent. methylene chloride. The absence of a third letter is a sign that methylene chloride is used as a solvent. In cases where other solvents are employed a third letter is added. PCD.13, for instance, is a cement containing 13 per cent. post-chlorinated P.V.C. and 87 per cent dichlorethane.

The Germans recommend the following cements:—

PC.10 (10 per cent. post-chlorinated P.V.C.
90 per cent. methylene chloride)
for bonding rigid, unplasticized P.V.C. foil to metals.

PC.20 (20 per cent. post-chlorinated P.V.C.
80 per cent. methylene chloride)
for the cementing of fittings, tubes, flanges and the like.

PCA.20 (20 per cent. post-chlorinated P.V.C.
80 per cent. acetone)
for cementing rigid, unplasticized P.V.C. foil to concrete, brickwork and wood. PCA.20 is applied to the foil only whilst PC.13.AM is brushed on to the supporting structure—concrete, etc.

PC.13.AM (13 per cent. post-chlorinated P.V.C.
15 per cent. cyclohexanone (anon for short)
72 per cent. méthylene chloride)
for the bonding of rigid, unplasticized P.V.C. foil to concrete, brickwork and wood (supporting structure only). This is one of the oldest German cements and its nomenclature is not in line with the coding system later adopted.

PCD.13 is nowadays used for the cementing of rigid P.V.C. pipe joints, but cements PC.20 and PCA.20 can be employed for the same purpose quite satisfactorily. PCD.13 is very often employed instead of PC.13.AM for the lining of steel tanks, concrete and wooden vats with plasticized P.V.C. sheet.

All these cements have a limited shelf life and should be stored at a low temperature. Cements which have thickened up in storage can be diluted to a certain extent with the proper solvent, but this procedure

is not recommended for lining operations where new and undiluted cements give best results.

German P.V.C. cements for lining metal containers and the like suffer from the drawback that the metal surfaces have to be preheated to rather high temperatures, 285° F. (140° C.) which is in many cases impracticable. Cements based on similar formulations suffer from the same drawback, except the American cements mentioned in Chapter XIV (lining of tanks with plasticized P.V.C.); these can be used without preheating.

German cements are supplied by Dynamit A.G. Troisdorf and the Badische Anilin & Sodafabrik (BASF) Ludwigshafen and their subsidiaries.

Cements developed by Imperial Chemical Industries Limited in Great Britain under the name of Tensol 50, by Chemidus Limited, London (cement No. 2A1), the B.B. Chemical Company Limited of Leicester and by various firms in Italy, France and the United States are formulated on lines similar to those used for German cements. They, too, have a limited shelf life of 3 to 4 months; they can be diluted with solvents, for instance methyl-ethyl-ketone; some of them can also be used to bond plasticized P.V.C. to steel, to concrete and to wood.

The deciding factor in the selection of a P.V.C. cement is its peeling strength measured by peeling a bonded strip from a drum, Fig. V/1. Details of measuring the adhesive strength by the so-called climbing

FIG. V/1.—Stripping apparatus for measuring the peeling strength of polyvinyl chloride cement.

peel test have been described by Warren and Eickner in *Modern Plastics* (*6*).

Various other cements have been suggested, for instance, one by Ruebensaal (*5*), who proposed the coating of the surfaces to be bonded with solutions containing vinyl chloride, vinyl acetate, maleic acid, methyl-methacrylate, in a methyl-methacrylate monomer. A cement for welding and bonding of P.V.C. supplied by the General Anilin & Film Corporation, New York, consists of an ammonium salt of a copolymer of a methyl vinyl ether and maleic acid anhydride. It can be condensed with formaldehyde (*1*).

For bonding at ordinary room temperatures Been (*2*) suggests an epoxy cement. Blake (*4*) proposes for the bonding of plasticized P.V.C. to steel, a copolymer adhesive with a semi-rigid or rigid P.V.C. layer inserted between plasticized P.V.C. and adhesive to stop migration of the plasticizer which would destroy the adhesive.

The fundamentals of tackiness and adhesion are discussed by Bikerman (*3*).

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CHAPTER VI

HISTORICAL DEVELOPMENT OF THE WELDING OF POLYVINYL CHLORIDE

THE WELDING of thermoplastic materials and the large scale use of P.V.C. was a logical development brought about by historical events.

Shortage of non-ferrous metals in the years following Hitler's assumption of power in 1933 caused German chemists and technicians to search vigorously for substitute materials; copper, nickel, tin, chromium and manganese had to be imported and were urgently required for rearmament; the largest and most powerful group of chemical firms—the I. G. Farbenindustrie A.G. had a decisive influence on economical problems—and they were, therefore, leading in the search for new materials.

Polyvinyl chloride became available on an industrial scale in 1935; soon afterwards it was discovered that unplasticized P.V.C. could be moulded, extruded and heat-formed provided it was properly stabilized.

Further research work revealed that polyvinyl chloride could be welded under simultaneous application of heat and pressure.

The first successful welding experiments were carried out by Henning and his team and I. G. Farbenindustrie A.G. applied for a patent to protect Henning's invention on May 1st, 1938. Extensive patent coverage was sought in many other countries and a patent application was also made in Great Britain in April, 1939.

The outbreak of World War II delayed the work in Patent Offices all over the world; Henning's patent was accepted in 1943 (D.R.P. 739.340) (*2*) whilst the corresponding Patent application in Great Britain was held pending for the duration of the war and was subsequently declared void.

Further development work by Voigt (Halle), Dammer (Leverkusen) and Krannich (Ludwigshafen) led to large scale applications of P.V.C. in the Chemical Industry, in fact all the factories of the I.G. Farbenindustrie group became a huge proving ground for rigid polyvinyl chloride and also for welded fabrications in this material.

The publication of Krannich's book *Vinidur und Oppanol im Technischen Korrosionsschutz* in 1943 gave the first comprehensive account on the use and handling of both polyvinyl chloride and polyisobutylene.

The welding of rigid polyvinyl chloride was introduced by the Germans in all occupied countries in the earlier stages of the war.

Co-operation between the various Research Teams in Leuna,

Bitterfeld, Leverkusen, Ludwigshafen and other places ceased at the end of hostilities in 1945. Germany was partitioned into four zones and little or no contact was made between factories situated in other zones.

Various teams of allied investigators went to Germany in the course of 1946 and 1947 to study war-time developments and a special team reported about the 'Welding of Plastics in Germany', BIOS report No. 1839 (*1*).

Henning went to America to continue with his work and most of the experts in the Eastern Zone of Germany gradually emigrated to the West.

Krannich, whose book is still considered the bible of all plastic fabricators, died in 1951.

Most of the historical details given above are well known to everybody concerned with the welding and fabrication of rigid polyvinyl chloride. There is a firm belief that all the work concerning the welding of plastics was based on German experience and know-how. This, however, is not correct.

It is little known that Reinhardt, an American employed by the Dow Chemical Company, applied for a patent for a welding process for thermoplastic materials on November 20th, 1937 (U.S. Patent No. 2,220,545) (*1*), i.e. almost six months earlier than Henning.

Both inventions are almost identical in their scope. Little or no use was, however, made of Reinhardt's invention, most probably due to the fact that the Americans could not see the necessity for using polyvinyl chloride or polyvinylidenechloride for the construction of chemical plant.

Welding of plastics in Great Britain was approached from an entirely different point of view. The author of this book became aware of German attempts to weld plastic materials through a note in the *German Patent Gazette* sometime in April, 1939. This note recorded the mere fact that Dr. Henning of the I. G. Farbenindustrie A.G. had applied for a patent covering a welding process for thermoplastic materials. Further details, for instance, of the method employed, were not given, nor could they be obtained elsewhere.

The author, who was then employed as a research chemist by the Arc Manufacturing Company Limited, obtained the permission of his managing director, the late Dr. J. H. Paterson, to commence work on the welding of plastics. Early attempts in this field remained unsuccessful, however, as the various types of polyvinyl chloride, cellulose acetate, etc., then available proved to be unweldable.

The development programme was split later—the author carrying on with gas welding and heated tool welding—whilst his colleague, Dr. H. P. Zade, pursued work in a different direction—using an old diathermy set, co-operating with Jarrard and Moritz. Their work led to the invention of high frequency welding for which the first patent

in their name was applied for in August, 1941 (Br. P. No. 555,054). This patent is older than any other patent in the field of High Frequency welding (*3*).

The existence of a research team working on the welding of plastics was known to the authorities and in 1942 an enquiry was received by the author requesting help in the jointing of a white, unnamed material.

The author was able to weld the components submitted and this was probably the first successful attempt at welding polythene.

Recent developments

The basic methods of welding polyvinyl chloride have not basically changed since their inception, but materials have vastly improved—suspension polymers are used instead of emulsion polymers; the equipment, too, has been improved and automatic welding machines have become available and research work by the Plastics Institute at Aachen has led to a better understanding of the welding process proper.

In short, the welding of polyvinyl chloride has become a recognized method of fabrication.

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CHAPTER VII

WELDING EQUIPMENT

Welding torches

The development of torches for the welding of rigid and plasticized P.V.C. was rather slow until quite recently.

The first torches were designed by Henning and later perfected by Griesheim-Autogen, and Schrupp, Germany.

There are two basically different types of torch, the gas operated type and the electrically heated type.

Gas operated torches are in some cases preferred as they do not require replacement of the heater element; on the other hand, gas operated torches require a regular supply of acetylene, hydrogen, etc., and they are awkward to use in confined spaces, for instance, the welding of corners in a tank.

The basic principle for both types of torch is the same; compressed air or an inert gas, such as nitrogen, is passed through a heater element which increases the temperature of the gas to approximately 280° C. measured $\frac{1}{4}$ in. away from the nozzle tip. The welding gas should be under a pressure of 5 to 8 lb.

The volume of welding gas required varies according to the size of tip used, but 15 to 30 litres of compressed air will give the best results.

Gas-heated torches

Fig. VII/1 shows a typical gas-heated torch; its heater coil consists of a stainless-steel tube through which the welding gas passes. It is

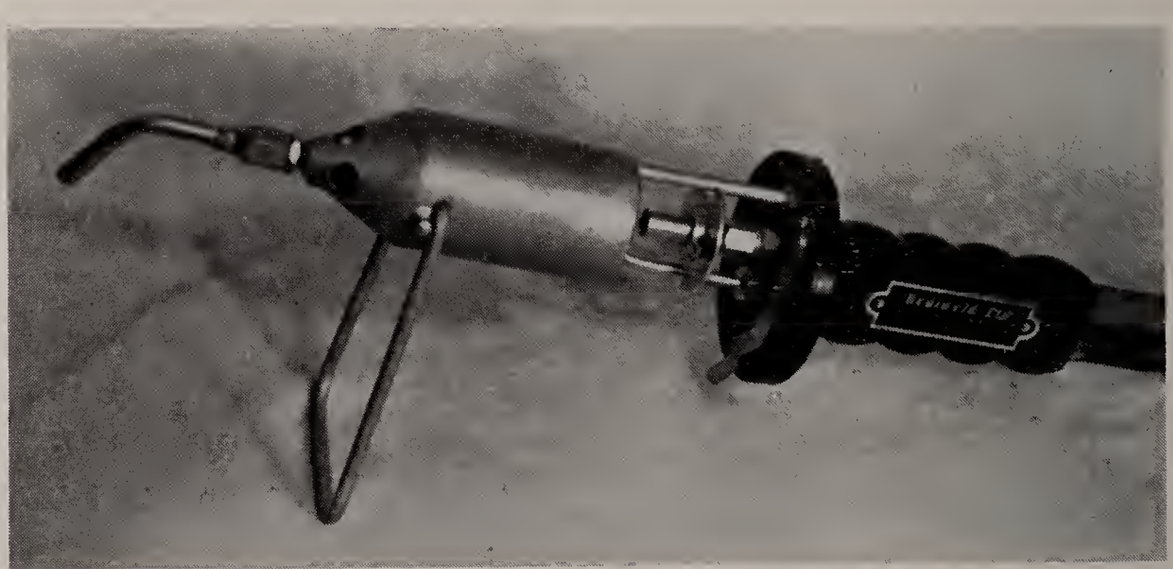

FIG. VII/1.—Gas-heated welding torch.

surrounded by a heat-insulating shield to prevent thermal losses. The outlet of the heater coil connects to a welding nozzle which can be exchanged in accordance with the thickness of the material to be welded. A special feature of this particular torch is the baffle plate fitting over the injector thus preventing a 'blow-back' when welding in an inverted position. The collapsible stand fitted to the torch can be swung back and be retained by a spring clip so that it should not impede the welding operation. It is possible to remove the collapsible stand altogether by spreading the two sides of the support where it is hinged to the body. This torch weighs 18 oz. without tubing.

The method of operation is as follows:

(1) Connect the welding gas supply (nitrogen or compressed air) by means of a rubber hose or plastic tubing to the inlet leading to the heater coil;

(2) Connect the heater gas supply (acetylene, hydrogen, propane or butane) to the other inlet;

(3) Turn on the welding gas;

(4) Ignite the heater gas flame;

(5) Adjust the flame until the inner cone is approximately $\frac{1}{4}$ in. long. A yellow flame indicates insufficient air intake which may be caused either by excessive acetylene pressure or by the blocked air inlet of the injector.

The acetylene supply should be turned off when terminating work and welding gas should be passed through the heater coil for at least five minutes. After that, the supply of welding gas can be switched off. There is hardly anything that can go wrong with this type of torch and the stainless-steel heater coil has an almost indefinitely long life. It is, however, necessary to clean the injector and the gas-jet periodically. The cleaning of the jet in particular requires some manual skill; no attempt should be made to push a wire through the opening as this may ruin the jet. It is always recommended to carry a few replacement jets in stock.

The standard model of this type of torch is designed for work with acetylene. Models suitable for hydrogen, propane or butane gas can be supplied; alternatively, the standard model can be modified for this purpose by fitting appropriate injectors and nozzles. Acetylene-operated torches are mainly used in workshop whilst for work on site the use of butane or propane gas in bottles is indicated, as they are easier to transport.

It should be noted that under proper working conditions three individual flames will emerge through the holes in the conical top part of the protective cover. These flames, however, should not be longer than approximately $\frac{3}{4}$ in.

Approximate Gas Consumption: Acetylene: 36 l/h
Hydrogen: 120 l/h
Town Gas: 110 l/h
Compressed air: 900–1,800 l/h.

The Udylite torch, used for the lining of tanks with plasticized P.V.C., operates with hydrogen and compressed air (*3*, *4*). Further details of this torch are given on page 148.

Electrically-heated torches

There are several distinctively different makes of electrically-heated torches on the market. Most of these share the same basic principle, i.e. they have a heating element, consisting of a ceramic body on which or through which resistance wires are placed. They differ slightly in weight, wattage and efficiency.

It should be borne in mind that the method of operation requires an oscillatory movement of the tool, upwards and downwards, different from that being practised in metal welding. It is therefore not recommended to copy the design of welding torches for metal welding or to imitate electrode holders. Proper balancing is of importance.

Fig. VII/2 shows a typical electrically-heated torch of medium wattage. It can be supplied with elements for 42 volts, 110 volts or 220 volts. The 42-volt model is specially recommended for use in chemical factories where wet floors may prove fatal to an operator handling a mains voltage tool which may have developed an insulation fault.

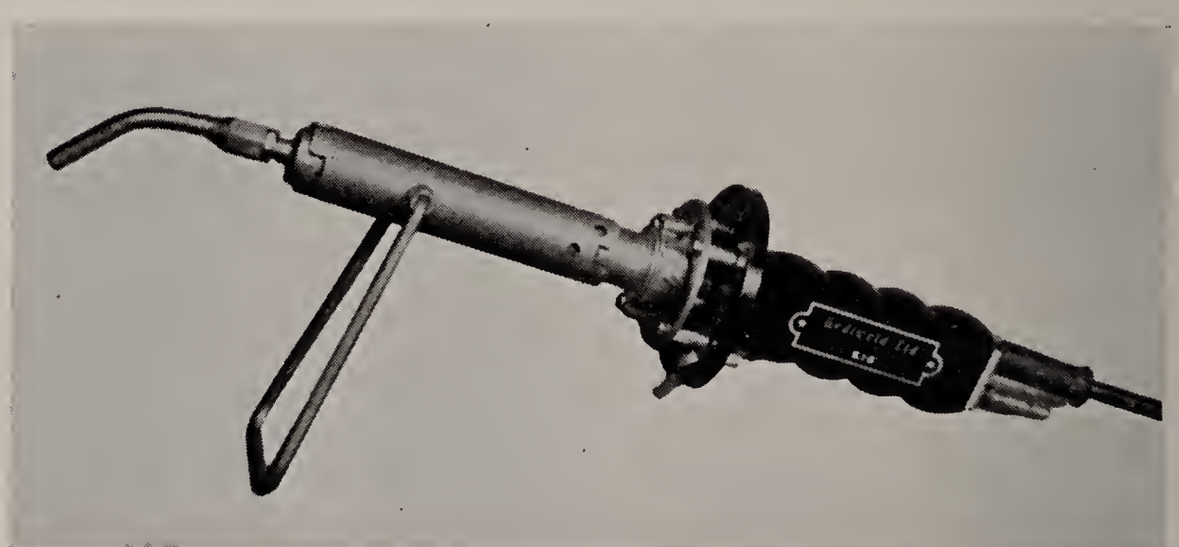

Fig. VII/2.—Electrically-heated welding torch (with ceramic heater element).

The ceramic heater element of this torch can be exchanged in a few minutes by unscrewing the two retaining screws, lifting the insulating shield and disconnecting the burnt-out heater element, afterwards reversing the whole process when inserting the new element. Such

torches can be used for a considerable time provided they are not dropped accidentally. Furthermore, a steady stream of gas should pass through the heater element for at least five minutes before switching on the current or after switching it off. Most torches of this type are ruined through carelessness, i.e. forgetting this simple rule.

The most troublesome part in most electrically-heated welding torches is the ceramic heater element which cracks when the torch is accidentally dropped on a concrete floor. Moisture and oil from the compressor accumulate in the supply lines and eventually reach the hot element, which obviously then perishes.

Oil and water filters should therefore be inserted into the compressed air line; these filters should be inspected and cleaned at frequent intervals—otherwise they will become useless.

A new type of electric welding torch which is less troublesome in use has recently come on the market. It contains a metallic heater element, which does not crack on impact, neither is it very sensitive to water and oil. Fig. VII/3 shows this new torch. Like most electrically operated torches it is light in weight (24 oz.) and well balanced.

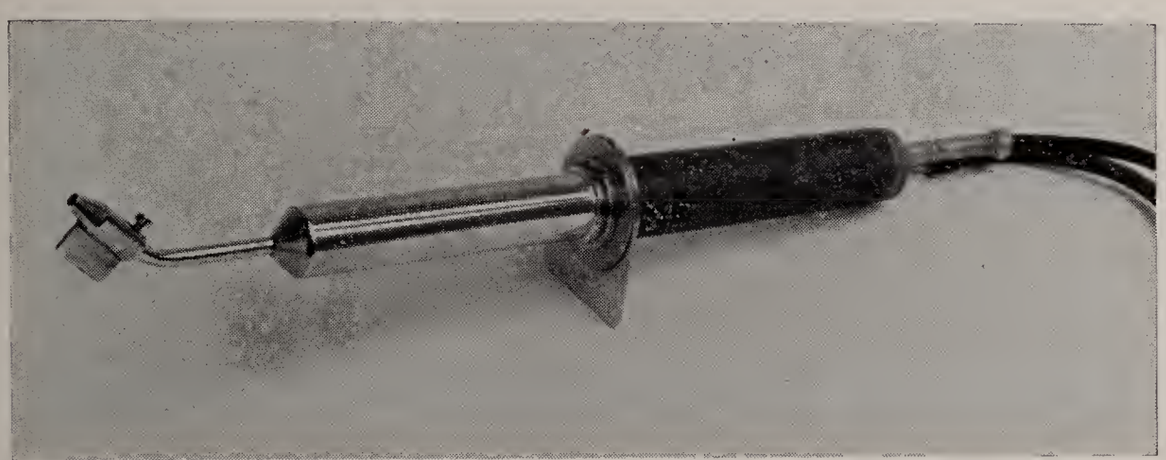

Fig. VII/3.—Electrically-heated welding torch with sheathed heater element.

Special attention should also be given to the electrical connections of electric torches as accidental dropping may cause fracture of the ceramic parts when the wire leads may become free and cause shorts. It is necessary to insulate the handle to the fullest extent; care should also be taken that the handle does not overheat, which unfortunately is the case with some torches.

It is of advantage to provide some kind of support on electric torches as welders sometimes forget to switch the current off, leaving the heated gun lying on the bench, or, even worse, on a piece of plastic material, thereby causing serious risk of fire.

Some torch manufacturers recommend the use of rheostats (variacs) with their torches, to enable the operator to control and set the temperature of the welding gas within desired limits. Rheostats are an

unnecessary refinement, as the welder can always increase the distance between torch and work piece; the temperature of the welding gas will then drop very sharply. The supply of gas (compressed air or nitrogen) must, however, be sufficient to shroud the filler rod and the base material; there should be sufficient pressure (at least 5 p.s.i.) and a volume of gas should be not less than 15–20 litres per minute.

Quite recently torches with a built-in blower have appeared. They are quite useful for small scale operations, for instance for repairs, but they are far too heavy to be used for continuous work. They weigh approximately 3 lb. against 24 oz. in the case of ordinary electric torches.

Advantages and Disadvantages of Both Types of Torches

Gas-heated torches

Advantages:

Light weight;
Few replacements;
Independence of power supplies.

Disadvantages:

Cannot be used in confined spaces or on premises where open flames are not permissible;
Cannot be used for tank lining as the heater flames penetrate through the protective cover causing overheating of the plastic in the corners.

Electrically-heated torches

Advantages:

Less drag on the operator's hand (only one length of tubing and one cable carried);
Risk of explosion avoided;
No irritating gases emitted.

Disadvantages:

Risk of holding a live tool in hand unless a low-voltage supply (transformer) is used.

Automatic torches

Automatic torches were already considered in the earlier stages of development; an experimental machine was first developed by the Kunststoffe Institut of the Technische Hochschule at Aachen. Peukert (*2*) described the results achieved with this machine. Further development work by Schulz (*6*) led to the semi-automatic and automatic Ascomat machines manufactured by Aug. Schnakenberg & Co. in Germany; Rediweld Limited, England, sell identical equipment under the name of REDIMAT.

By using these machines far greater speed can be achieved than by ordinary hand welding. The semi-automatic ASCOMAT/REDIMAT machines deposit between 12 in. and 15 in. of weld per minute. Using trangular filler rod the deposit is very much heavier than by hand welding, i.e. a single weld produced on one of these machines can replace up to 3 single runs laid down by hand welding. As ordinary hand welding yield no more than 5 in. per minute, the speed of welding is, in fact, nine times that of ordinary hand welding.

Both types of machine can be used with advantage for the welding of duct work.

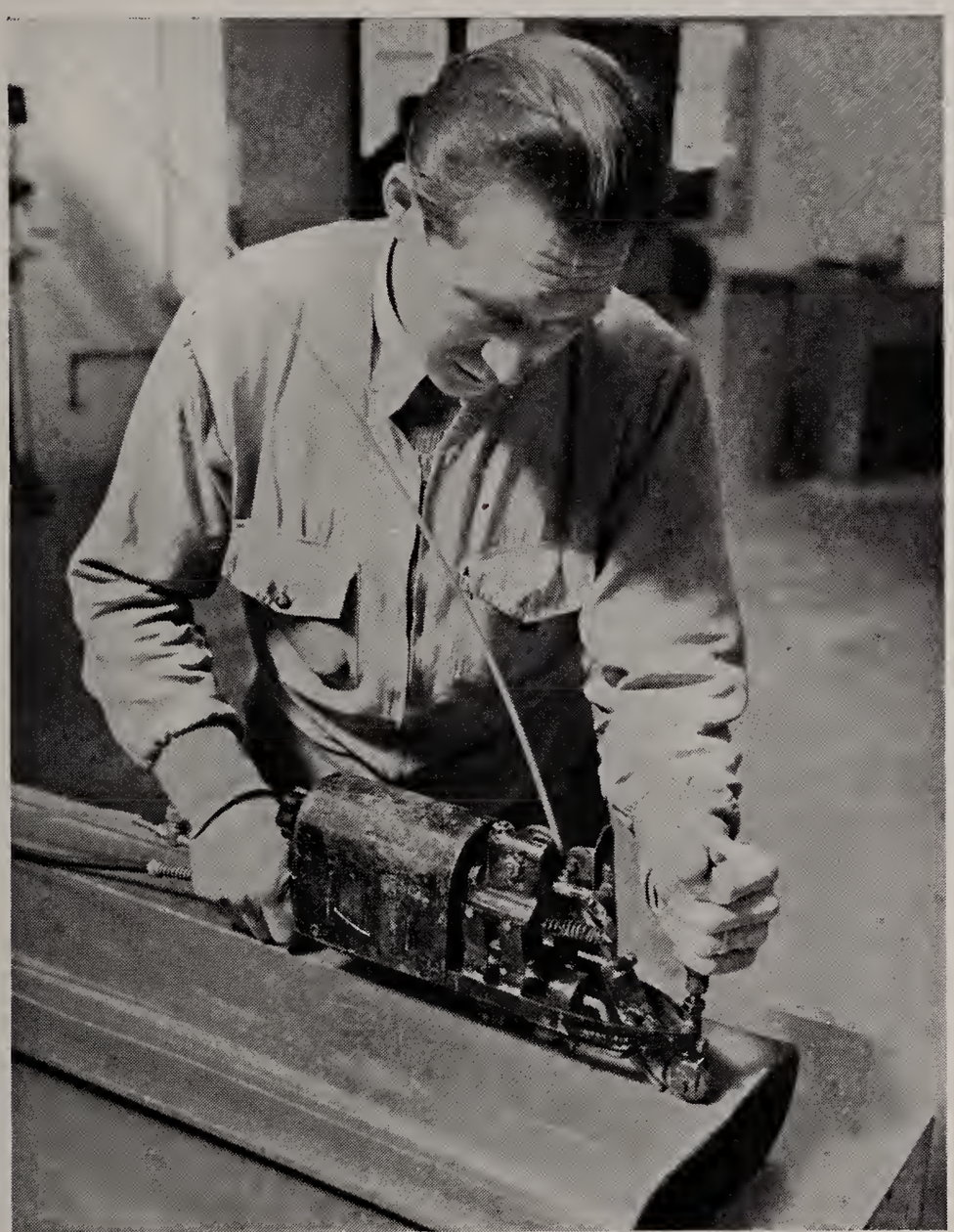

FIG. VII/4.—Redimat-Ascomat semi-automatic welding machine.

Fig VII/4 shows a semi-automatic machine of the ASCOMAT/REDIMAT type in operation. Fig. VII/5 illustrates an automatic machine mounted on rails, together with a special welding bench.

A cross section through a weld produced on one of the machines

clearly illustrates the advantages of machine welding: uniform cross section, freedom from undercut, neater appearance and absence of warping or distortion of the parent material.

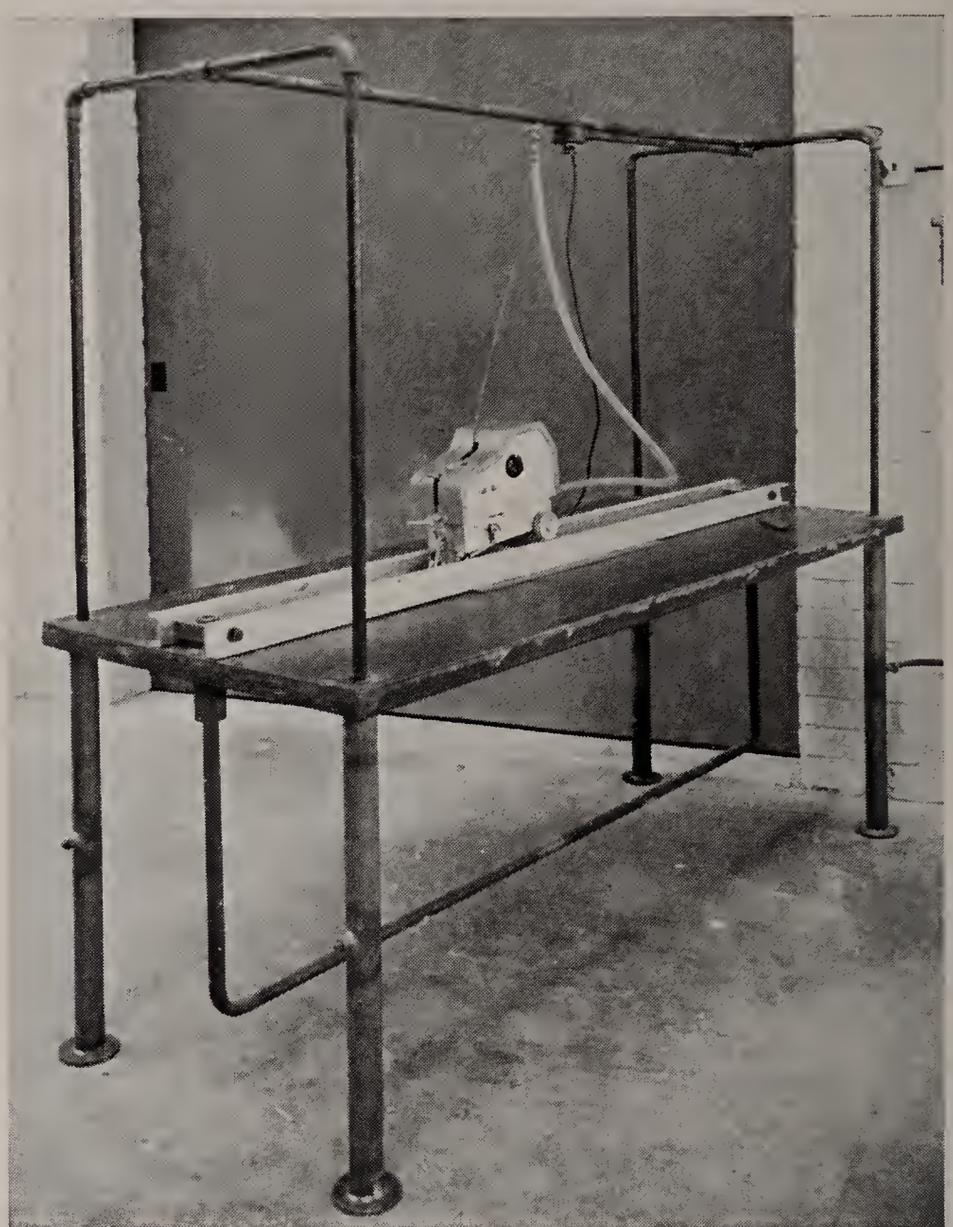

FIG. VII/5.—Redimat-Ascomat fully automatic welding machine on pneumatic operated welding table.

The better mechanical values of an automatic weld are mainly due to the absence of inclusions or burned material, nearly always found in welds produced by manual welding.

Fig. VII/6 shows cross sections through an automatic and a manual weld.

A relatively simple automatic welding torch, the so-called H.G.A. torch, was developed by Z.I.S. (Zentral Institut fur Schweisstechnik Halle/Saale, D.D.R.) (*5*).

The H.G.A. torch consists basically of a carriage on rollers and a stand to which a cylinder with weights and a hot air welding torch are attached.

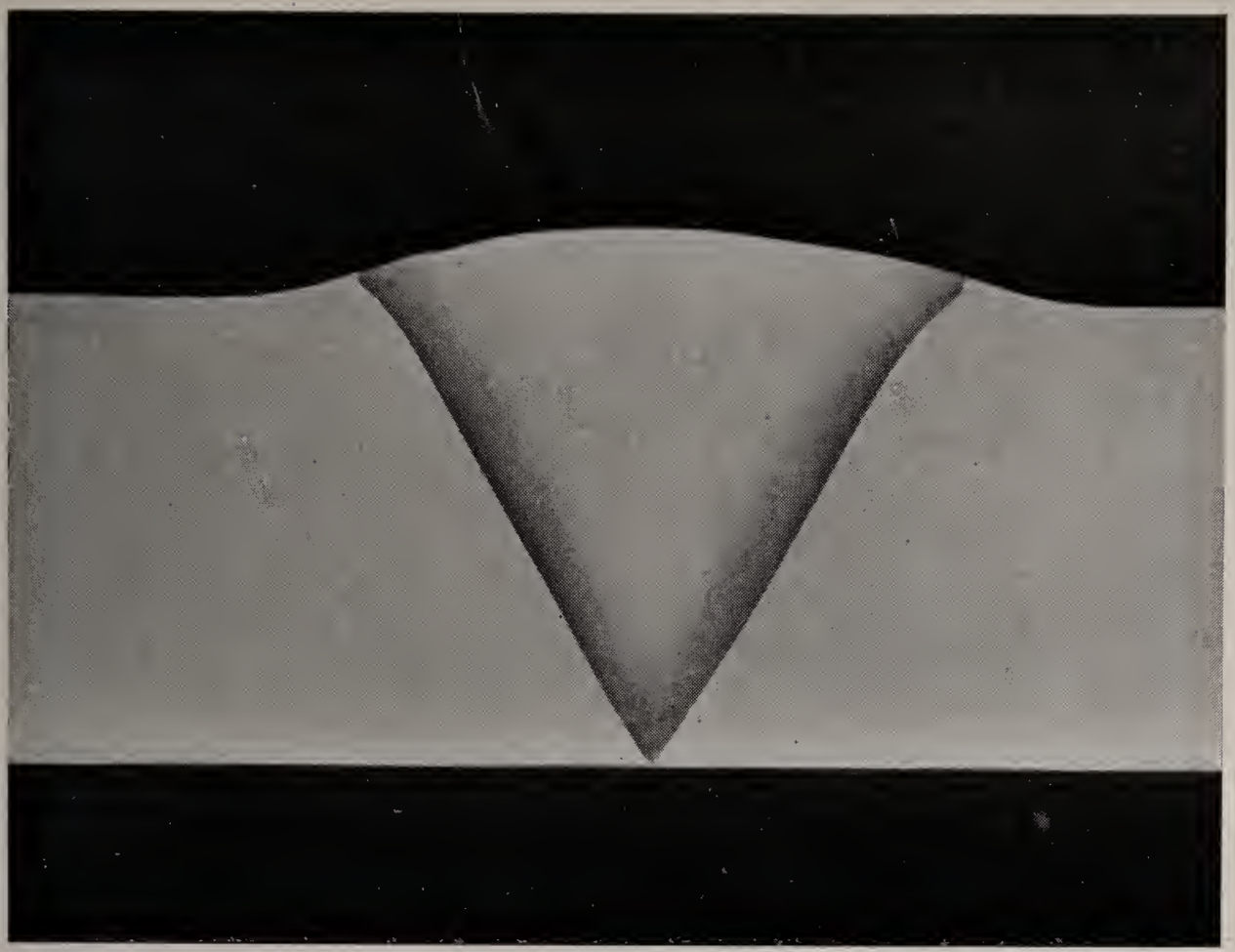

FIG. VII/6a.—Cross section through a weld produced on an automatic welding machine. (Note uniform appearance of welded material.)

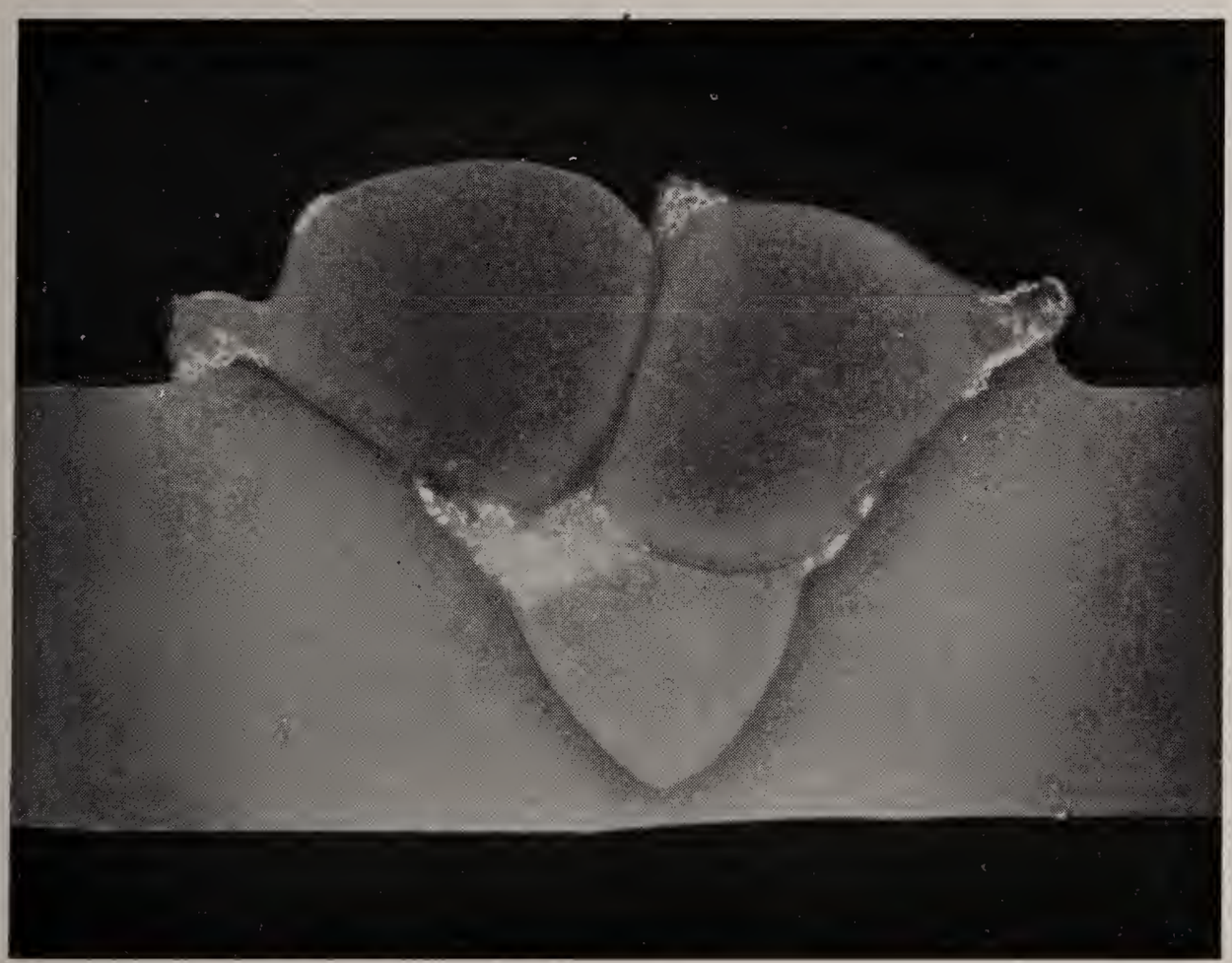

FIG. VII/6b.—Cross section through a manual weld in polyvinyl chloride. (Note air inclusions and burned material on the boundaries.)

Details of this machine are shown in Fig. VII/7.

Beginning from the top there is a length of P.V.C. filler rod (C) clamped (C) to a movable weight (B) which gradually slides down inside a hollow cylinder (A). A torch (H) is attached to the cylinder (A) with its nozzle (J) pointing down towards the seam.

The whole assembly is mounted on a carriage with two rollers (E) which are adjustable (they can be set under an angle to suit the contour of a cylinder or drum), and has a guiding roller (F) in front.

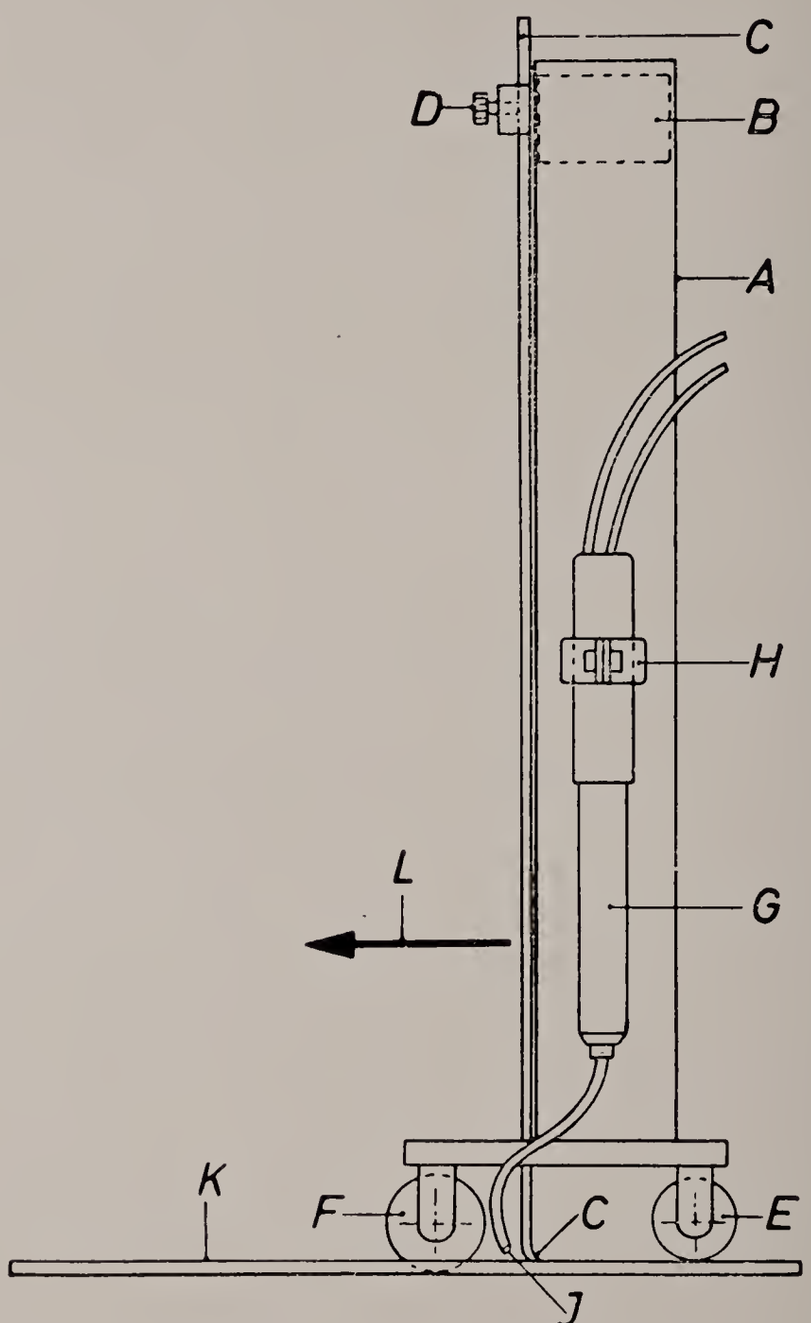

FIG. VII/7.—Schematic diagram of the H.G.A. automatic welding torch.

(a) Cylindrical container for movable weight (b).
(b) Movable weight.
(c) Polyvinyl chloride welding rod.
(d) Fitting for clamping welding rod to movable weight.
(e) Wheels.
(f) Guide wheels.
(g) Hot air torch.
(h) Clamps for welding torch.
(j) Nozzle of torch
(k) Polyvinyl chloride sheet.
(l) Indicates the direction in which the machine moves.

The device runs on rails and is, therefore, limited in its application. The movement along the seam is caused through the weight which in descending feeds the welding rod to which it is clamped; the welding rod fuses to the sheets to be welded and pushes the welding machine away from the start of the weld. (From right to left on Fig. VII/7.) Little is known about this machine in this country and it is probably not as dependable and flexible as the ASCOMAT/REDIMAT machine.

Triangular and round filler rods up to $\frac{1}{4}$ in. diameter are used on the H.G.A. machine, but they have to be preheated to 275° F. (135° C.) in an oven for 3-4 minutes for straightening; distorted filler rods cause jamming of the machine.

A hand-operated torch which is claimed to produce results similar to that of automatic torches, i.e. greater speed and uniform deposit, is produced by Laramy Products Company, Mass., U.S.A. This torch—the Kamlar torch—is very similar to ordinary electrically hand-operated torches, but it has a special nozzle with a guiding device for the filler rod. The claims for this torch are high deposition rate (up to 50 in. per minute). Care should however be taken to avoid stretching of the filler rod during the welding operation as excessive stretching would cause stress cracks on cooling.

Auxiliary Tools and Equipment

Transformers

Transformers have to be used with low-voltage torches. Fig. VII/8 shows a typical welding transformer with tappings for 220/110/42 volts. It can thus be used for either 220 or 110 volt mains. In many cases it is an advantage, especially for work in the field, to have a transformer which allows for the simultaneous connection to at least two torches. In such a case the wattage should at least be double that of one torch. It is, of course, necessary to provide for proper earthing of the transformer. A variac could also be used for the same purpose although it is somewhat more expensive. Variacs have the advantage that their output can be adjusted within reasonable fine limits.

Flowmeters

Experienced welders can readily judge whether their welding torch yields a stream of welding gas which is sufficiently hot simply by directing the nozzle of the torch against the palm of the hand. (Fig. VII/9). Beginners have not enough experience to judge the right temperature and although they may have measured the temperature and found that it was 280° C. $\frac{1}{4}$ in. away from the mercury bulb of the thermometer, they may still have difficulties on account of insufficient heat as variations in the velocity of the gas stream, i.e. an increased flow of gas, causes a drop in temperature at the same setting.

A flowmeter, as shown in Fig. VII/10, is of great help to the beginner. It consists of a small conically-shaped weight which floats inside a precision-bore glass tubing; its position inside the tube depends on the speed of the gas passing through. Flowmeters used for the welding of P.V.C. should cover a range from zero to at least 20 litres per minute. For the welding of Polyethylene a speed of 10 to 12 litres per minute is required, whilst for welding rigid polyvinyl chloride at least 15 litres per minute are necessary. After a few days' experience welders will be able to work without a flowmeter which then remains a useful tool for checking.

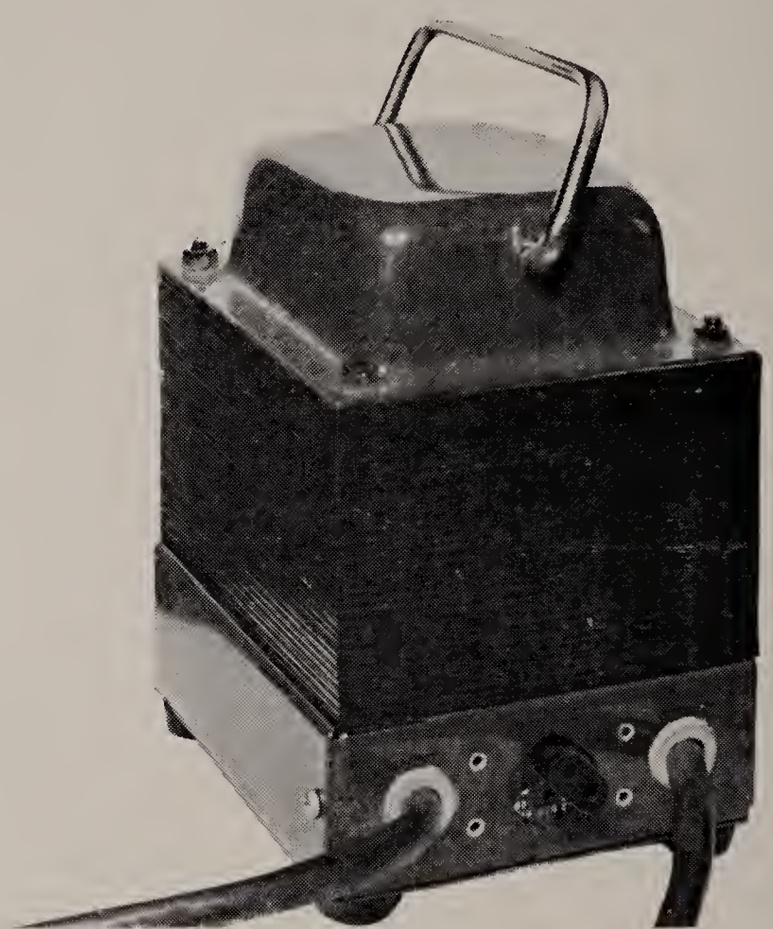

FIG. VII/8.—Welding transformer with tappings for 220/110/42 volts.

High frequency spark testers

A high frequency spark tester is a useful tool for testing the soundness of P.V.C. welds or P.V.C. linings.

It consists of a Tesla coil in a fully insulated housing with an exchangeable metal probe on top of the spark tester. This probe is either dome-shaped or carries a wire brush (up to 8 in. wide) for the simultaneous testing of larger areas.

Failures in a weld or a lining are indicated by a fat and noisy spark. Some skill is required to distinguish between an ordinary discharge

and a spark pure and proper indicating a void or porosity in the insulating material P.V.C.

Fig. VII/11 shows a spark tester with adjustable voltage range (3,000–26,000 volts). A very simple rule of thumb allows checking of the voltage—every mm. of gap bridged by a spark represents approximately 1,500 volts—3 mm. sparks represent therefore 4,500 volts, 18 mm. sparks 27,000 volts.

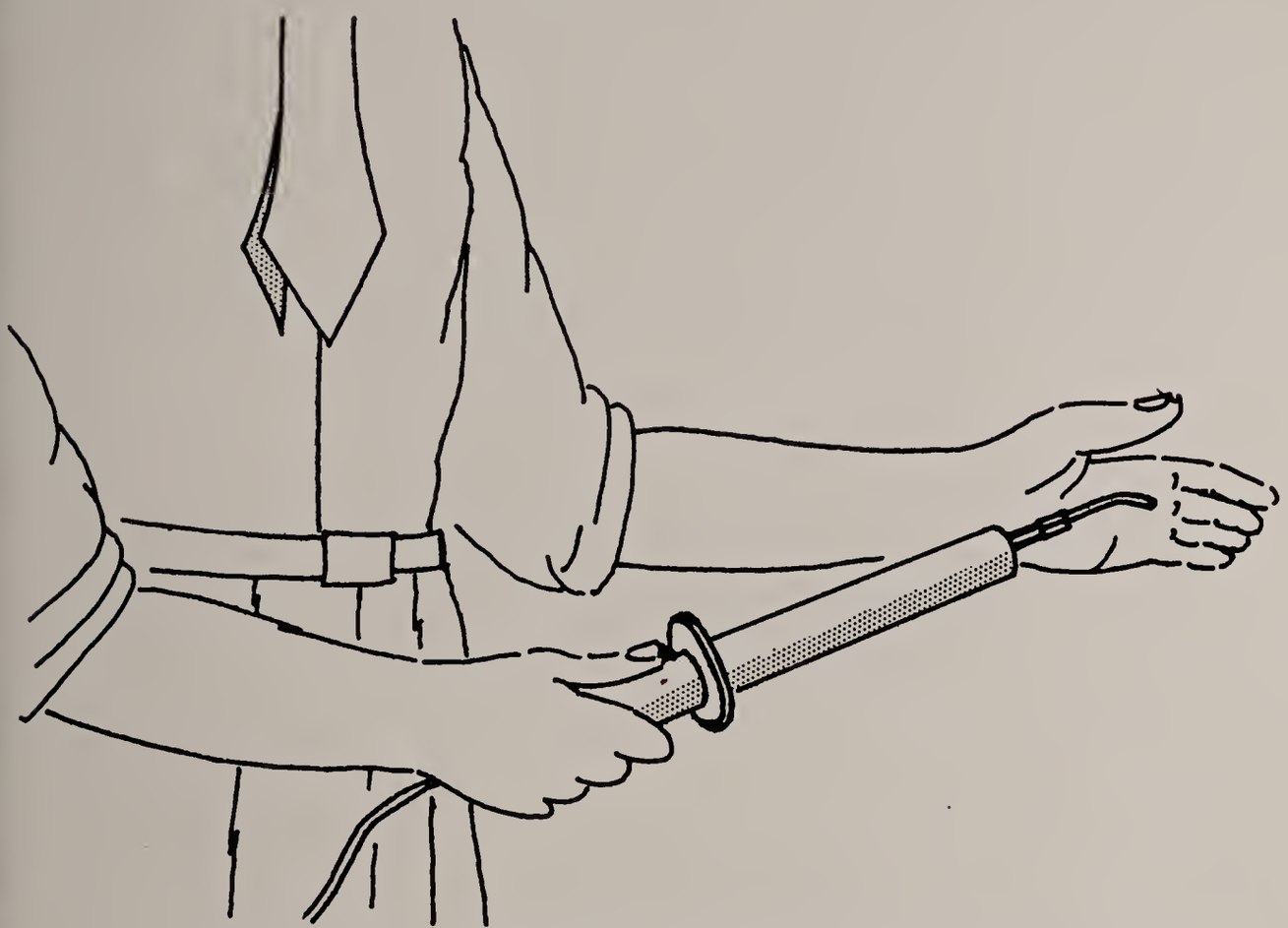

FIG. VII/9.—Ascertaining the right amount of heat.

P.V.C. is an excellent insulator but testing with excessive voltages will cause punctures, especially in thinner sections. It is therefore recommended to adjust the instrument to approximately 10,000–15,000 volts when testing rigid P.V.C. of heavier cross sections ($\frac{1}{8}$ in. and over) and to work at lower voltages—5,000–8,000 volts when testing plasticized P.V.C. linings (of any thickness) and linings made from rigid, unplasticized P.V.C. foil.

A new type of high frequency tester working on a D.C. supply was described by Becker (*1*). This instrument is less awkward to use than ordinary A.C. operated spark testers and accidental touching of the probe under charge does not result in slight shocks. Failures in a lining are shown on a Neon lamp.

This statement should not create the impression that A.C. operated spark testers are dangerous—although touching of the probe under charge is slightly painful.

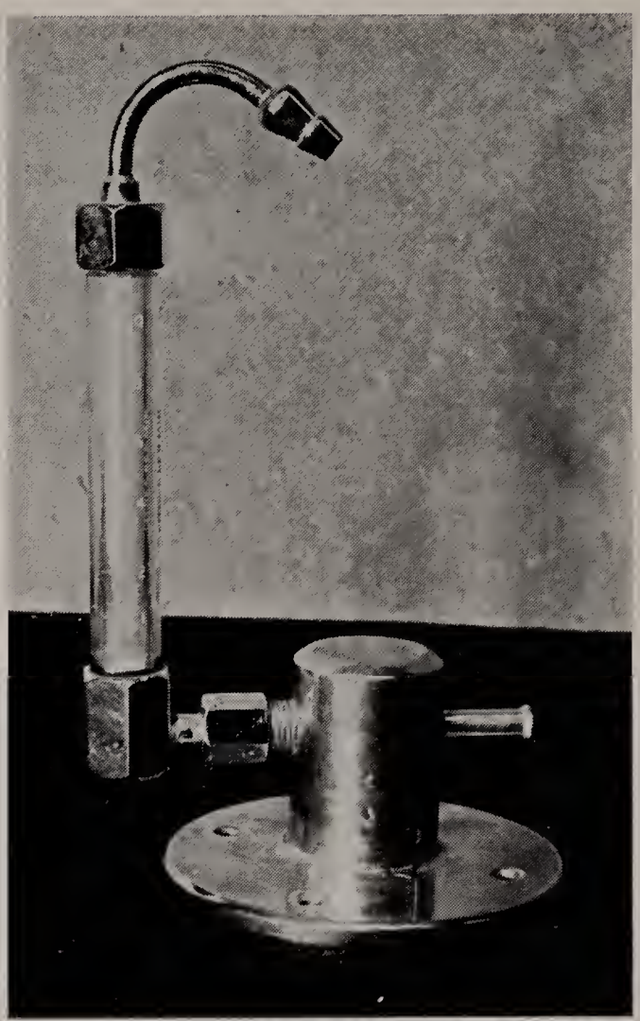

FIG. VII/10.—Flowmeter.

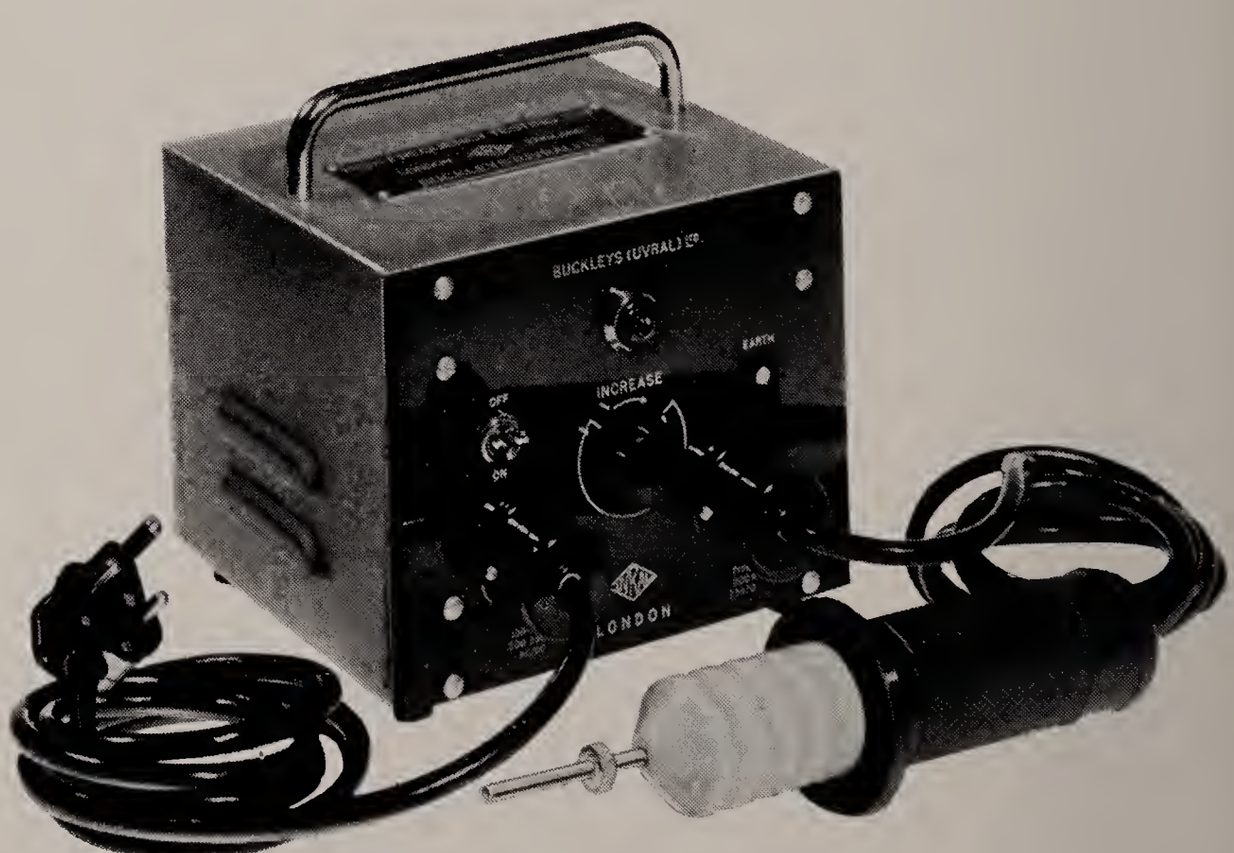

FIG. VII/11.—High frequency spark tester.

Other types of porosity testers

The presence of pores and voids in P.V.C. linings up to $\frac{1}{32}$ in. in thickness as well as porosity in lacquered, varnished or painted films can also be detected with probes (made from electrically conducting rubber using the Porosity Tester developed by Electro-Physik, Germany (D.P.B. No. 862,035)). Failures are indicated by a glow discharge on a Neon lamp. Connections to the metallic backing of the lining are not required which is of great advantage in cases where the backing is not accessible.

The M-1 Holiday detector made by Tinker & Rasor, U.S.A., works from batteries; the applied voltage never exceeds 68 volts. A damp cellulose sponge is used as inspection electrode and failures in a coating are indicated by the ringing of a bell. Mainly designed for the inspection of painted surfaces it can also be used for testing of relatively thin linings.

Nailing tools

Power driving tools such as the 'Supadynamic' Tool can be used for nailing into steel, concrete and brick-work—a technique which is rather useful for fixing rigid P.V.C. sheets to the inside of steel tanks or concrete vats and other types of larger vessels—to prevent excessive movement of the lining.

The heads of the nails are subsequently covered with P.V.C. dome-shaped covers which are attached to the P.V.C. sheet by circumferential welds.

Explosive charges are used to drive these nails or pins into the walls of the container.

Cutting and marking tools

A few sharp knives, files, rasps and scraping tools should be available on the bench of every welder; a fair selection of these is shown in Fig. VII/12.

Files

Rigid P.V.C. can be worked with ordinary files but these become clogged in due course and have to be cleaned at short intervals. The use of non-clogging files with removable blades (Fig. VII/13) results in considerable savings. A variety of blades with different settings is available.

The so-called 'development work' employed for the fabrication of large bore tube sections (lobster backs, T-pieces and the like), requires a fair amount of knowledge of geometry and technical drawing; the development of paper patterns, which are subsequently cut out and rolled around the tubes so that they can be cut accordingly, is a lengthy process and expensive.

FIG. VII/12.—Selection of knives, files, rasps, etc.

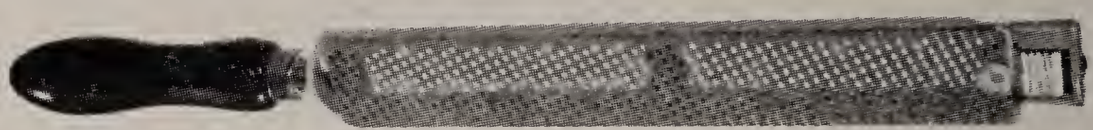

FIG. VII/13.—Non-clogging file with removable blades.

Special marking tools such as Contour Markers, the Jet Pattern Developer and similar tools can be used to advantage by skilled and unskilled workmen alike. These instruments eliminate paper patterns in many cases and save a great deal of time.

Centre gauges can be used to mark centre lines on the inside or outside surfaces of tanks and pipes under any desired angle. They can also be used to measure the degree of declivity of surfaces, to establish the centre of pipe intersections as well as to mark any point at any degree inside a large pipe or tank.

Plumbers springs

The bending of rigid P.V.C. pipes can be effected by various methods (see pp. 168–170). The filling of the pipes with sand, before bending, is an untidy operation and the use of plumbers springs is strongly recommended in its place. They are available in a range of sizes up to 2 in. diameter. Better still are springs covered with rubber to prevent damage to the inner wall of the pipes to be bent.

Punches

Concentrical gaskets in plasticized P.V.C. are usually punched out

in two consecutive operations. Unless great care is taken they are not truly concentric.

Patent Punches allow the simultaneous punching of both the inner and outer contours in 68 different sizes from $\frac{1}{8}$ in. to 2 in. outside diameter. Operation of these punches is simple and time saving. Larger gaskets are cut by means of trepanning tools.

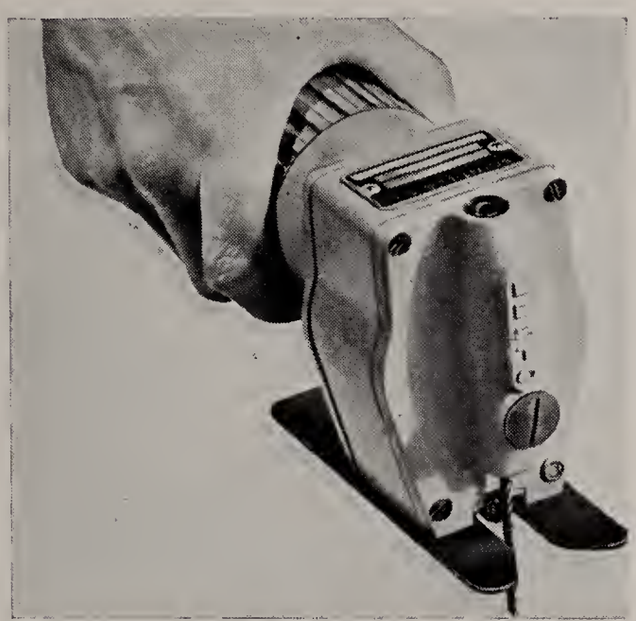

FIG. VII/14.—Scintilla saw.

Other hand tools

Apart from the tools mentioned above, the following should be available.

An ordinary carpenter's saw, one or two wooden mallets, a plumber's square, a plummet, a mitre block, a spirit level, steel rules, pliers, screw drivers, etc.

An electrically-heated kettle (glue pot) filled with oil is a useful item, in cases where belling (flaring) of rigid P.V.C. pipes for bell and spigot joints is contemplated.

A most useful and handy tool is a Scintilla saw (Fig. VII/14). It can be used for cutting out fairly complicated shapes from P.V.C. sheet up to 1 in. thickness and also for the cutting of holes in pipes.

Costs

The equipment for the welding of polyvinyl chloride is comparatively simple and inexpensive. An initial outlay of £100 will buy all the necessary tools for small operations; approximately £1,000 will be sufficient to obtain all the additional machines and tools for the fabrication of complicated pipe lines, duct lines and tank linings. This does not, of course, include the more expensive machine tools such as milling machine, a router or a lathe.

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CHAPTER VIII

OTHER WELDING PROCESSES SUITABLE FOR POLYVINYL CHLORIDE

MOST FABRICATION work in polyvinyl chloride requires some kind of welding. The hot gas method is universally applicable and it is therefore used to far greater extent than all other welding processes combined. This is the reason why this method is being discussed in this book in great detail.

The other welding processes are of minor importance especially for industrial applications. They are quoted in the following in alphabetical order.

Friction welding

The use of frictional heat for the butt-welding of P.V.C. was mentioned by Henning in 1942 (*4*). It fell, however, into oblivion but was rediscovered by Freres, an American, in 1946 (*1*). Henning's description of the process is quoted verbatim.

'The heat required for butt-welding of plastic pipes may be obtained by friction. An ordinary lathe is a suitable tool provided its tail stock has a live centre with a chuck. The two pipe sections are clamped into one chuck each and the lathe started. The tail stock chuck is held firmly by hand so that it cannot rotate whilst it is simultaneously pressed against the head stock, i.e. the other pipe end, clamped into the head stock chuck. Once sufficient heat is produced by friction the tail stock chuck is released and allowed to rotate, pressure still being maintained. The welded joint is then allowed to cool before the job is removed from the lathe. This method is most suitable for mass production'.

The heat for friction welding is produced by rubbing two parts against each other under simultaneous application of pressure. Such rubbing may be effected by a rotary or reciprocating motion. Air is practically eliminated from the rubbing surfaces and the formation of air bubbles, charring and oxidation of the material is therefore reduced to a minimum.

P.V.C. is a poor conductor of heat and the temperature necessary for bonding or welding (300°–400° F.) is reached almost at once without any risk of overheating. There is no necessity to clean the surfaces to be bonded prior to welding as any surface film or dirt will be squeezed

out in the course of the rubbing operation. The resulting flash, being thin and brittle, can be removed easily once it is cold.

A fair amount of pressure is required and as a rough guide it may be quoted that at least 100 lb./sq. in. are necessary. The entire operation, including chucking, seldom requires more than 30 seconds.

The components to be welded should be of similar composition, i.e. have approximately the same softening point, otherwise welding becomes much more difficult. Welding of different coloured parts leaves a clear and undistorted demarcation line in the centre.

The mechanical strength of a properly made friction weld is equal to that of the parent material.

The equipment for friction welding is very simple: drill presses, high

FRICTION WELDING AS APPLIED TO THE ASSEMBLY OF LENSES

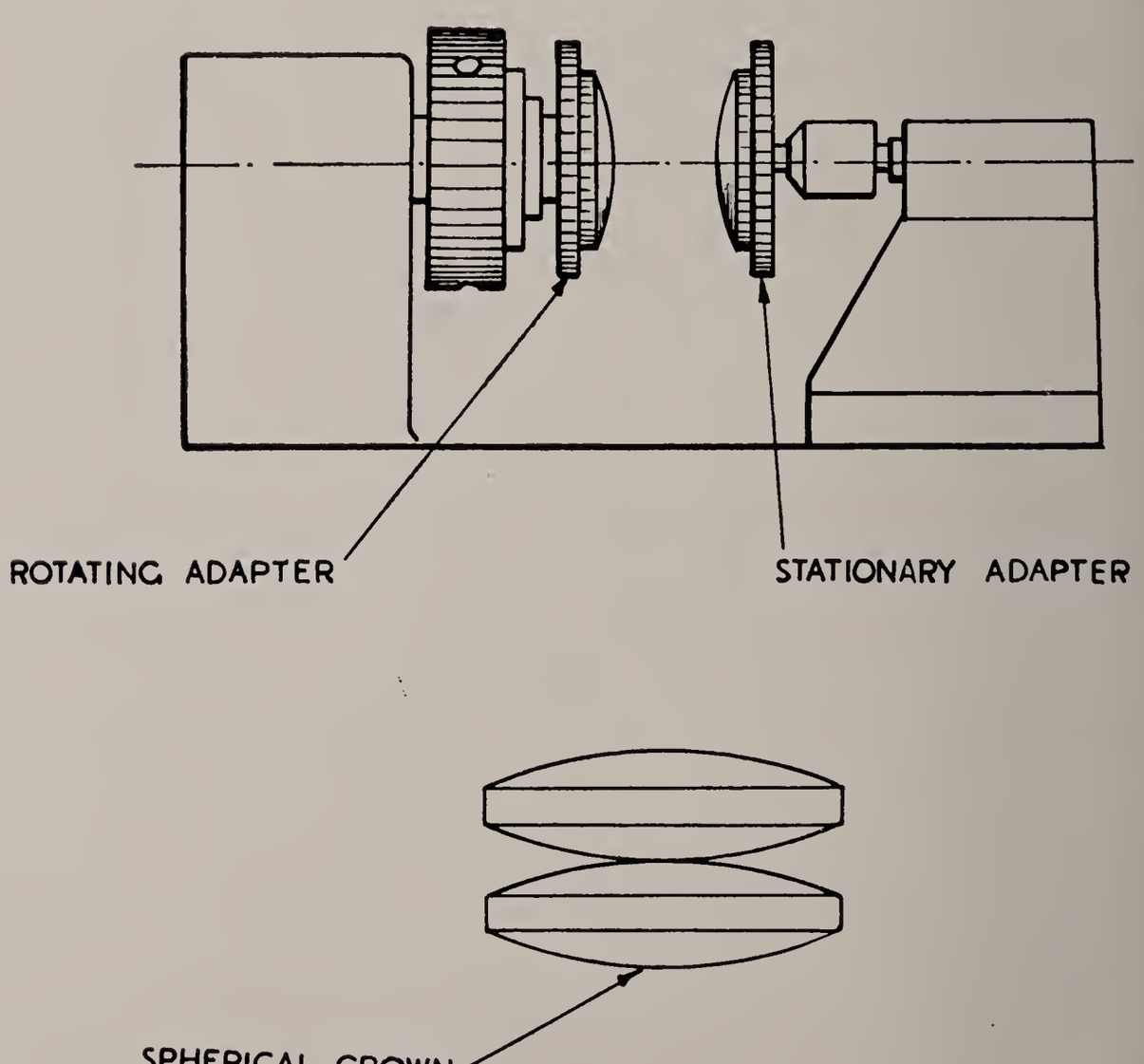

FIG. VIII/1.—Arrangement for friction welding on a lathe. (Note preparation of P.V.C. discs to be welded.)

speed drills or an ordinary lathe may be used for the welding of circular parts. Long cylinders may be produced by welding together the required number of rings of shorter length.

The rubbing velocity varies in accordance with the diameter of the components, for instance, for the welding of 3 in. diameter discs a velocity of 300 ft. per minute on the outer edges may be sufficient; for 6 in. diameter discs the speed has to be increased to at least 600 ft. per minute; such speeds are within the scope of an ordinary lathe running at approximately 375 r.p.m.

Friction welding is ideally suited for the joining of P.V.C. pipes as there is hardly any difference between the circumferential speeds at the inner and outer diameters of the pipes. Friction welding of solid discs is far more complicated and it should be borne in mind that there may be a rubbing velocity of, say, 600 ft. per minute at the outer circumference but velocity decreases towards the centre where it is practically zero; very little heat will thus be produced at that point. It is therefore recommended to provide the contacting surfaces of solid discs with a crown, see Fig. VIII/1, so that friction may develop first near the centre and gradually spread towards the outer edges.

For the welding of irregular shapes more complicated equipment is required; rubbing by reciprocating motion may be achieved by vibrators, oscillators or eccentrics.

Friction welding is a technique which is suitable only for mass production. This type of welding is useful in the manufacture of P.V.C. valves; the body of the valve is usually turned from solid rod which is not always available in larger diameters. It is therefore common practice in Germany to friction weld discs cut from blocks. The body of most German valves shows a clear demarcation line which is due to friction welding. Another application is the welding of rigid P.V.C. containers filled with liquids. It is immaterial whether these liquids are inflammable or not as the welding can be undertaken with the parts submerged.

Heated tool welding

Heated tool welding is seldom employed in the case of rigid polyvinyl chloride, but rather useful for the joining of plasticized P.V.C. Hot blades, heated rings or heated knives are brought into contact with the two surfaces to be welded—the tools are then withdrawn and the softened or molten surfaces are subsequently butt-welded or lap-welded together under pressure. (Fig. VIII/2.)

Rigid unplasticized P.V.C. has a tendency to char when in contact with hot metal surfaces and this is the reason why heated tool welding is rarely used for this material. Far less charring occurs in the case of plasticized polyvinyl chloride, due to the presence of plasticizers, and heated tool welding is therefore used to join the abutting edges of

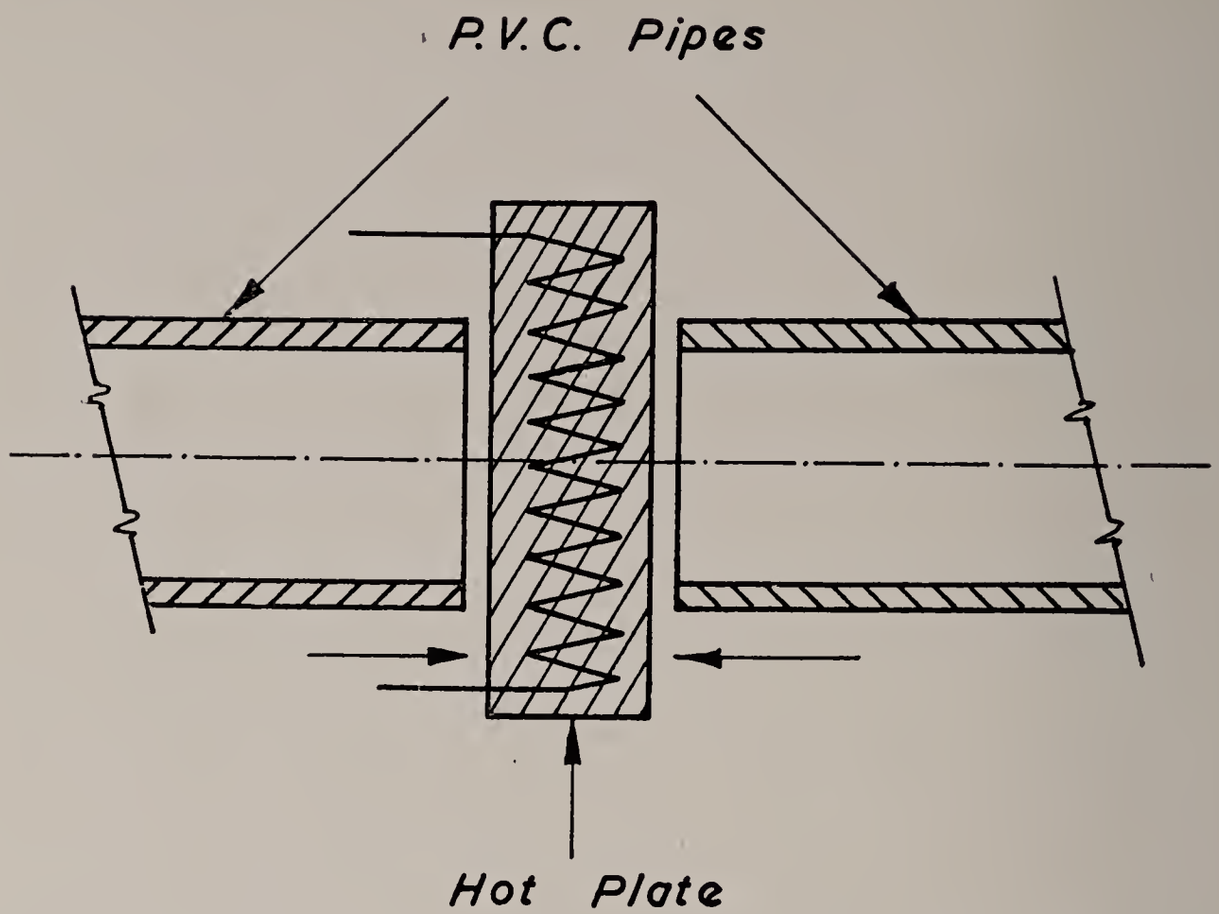

FIG. VIII/2.—Typical arrangement for heated tool welding.

plasticized sheets. The temperature of the welding tool has to be controlled by thermostats in cases where mass production is contemplated as overheated tools cause charring and destruction of the material. Fig. VIII/3 shows a typical heated tool which can be used for a variety of purposes such as the butt-welding of P.V.C. hand-rails, P.V.C. floors and tank linings. A follow-up roller is used for consolidation of the joint.

The fumes produced from the welding operation are very often acrid and disagreeable depending on the plasticizer used. Tricresyl phosphate,

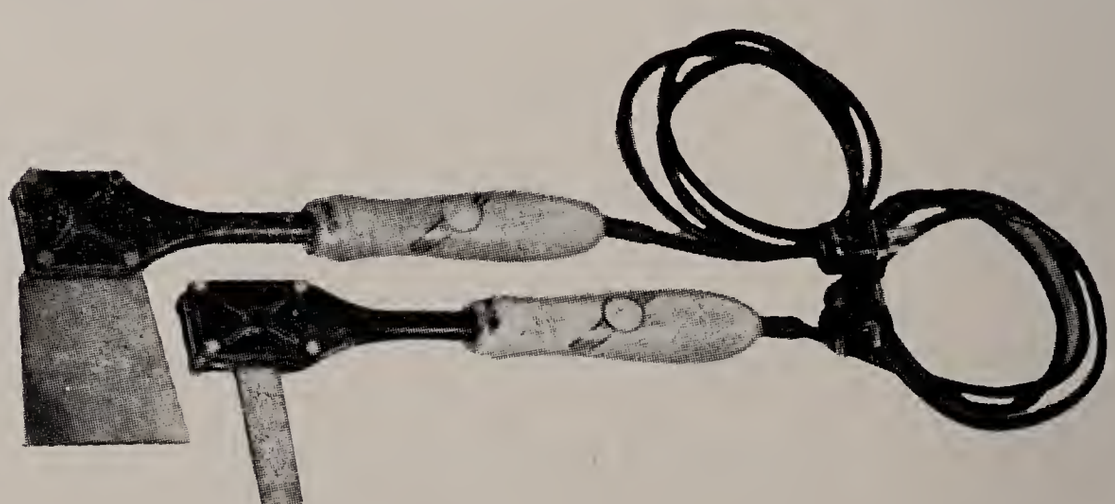

FIG. VIII/3.—Electrically-heated knives for butt-welding of polyvinyl chloride hand-rails, floors, etc.

for instance, may cause loss of appetite and symptoms resembling that of a heavy cold; it is interesting to note that the Germans have even coined a name for this effect which they call 'Igelit-catarrh' (*5*). Some people are affected by these fumes more than others and proper ventilation should be provided over the work benches where heated tool welding on plasticized P.V.C. is carried out on a larger scale. Absorption of these fumes by ammonia has also been recommended (*5*).

A semi-automatic machine for welding plasticized P.V.C. was developed by Siebel-Alter in Germany during the last war (*2*). Whether it did reach production stage is not known, it is certainly no longer in use at the present time. It uses the same principles as the semi-automatic machines (see Fig. VIII/4) for the welding of rigid P.V.C. except that heating is achieved by means of an electrically heated shoe instead of a hot gas torch.

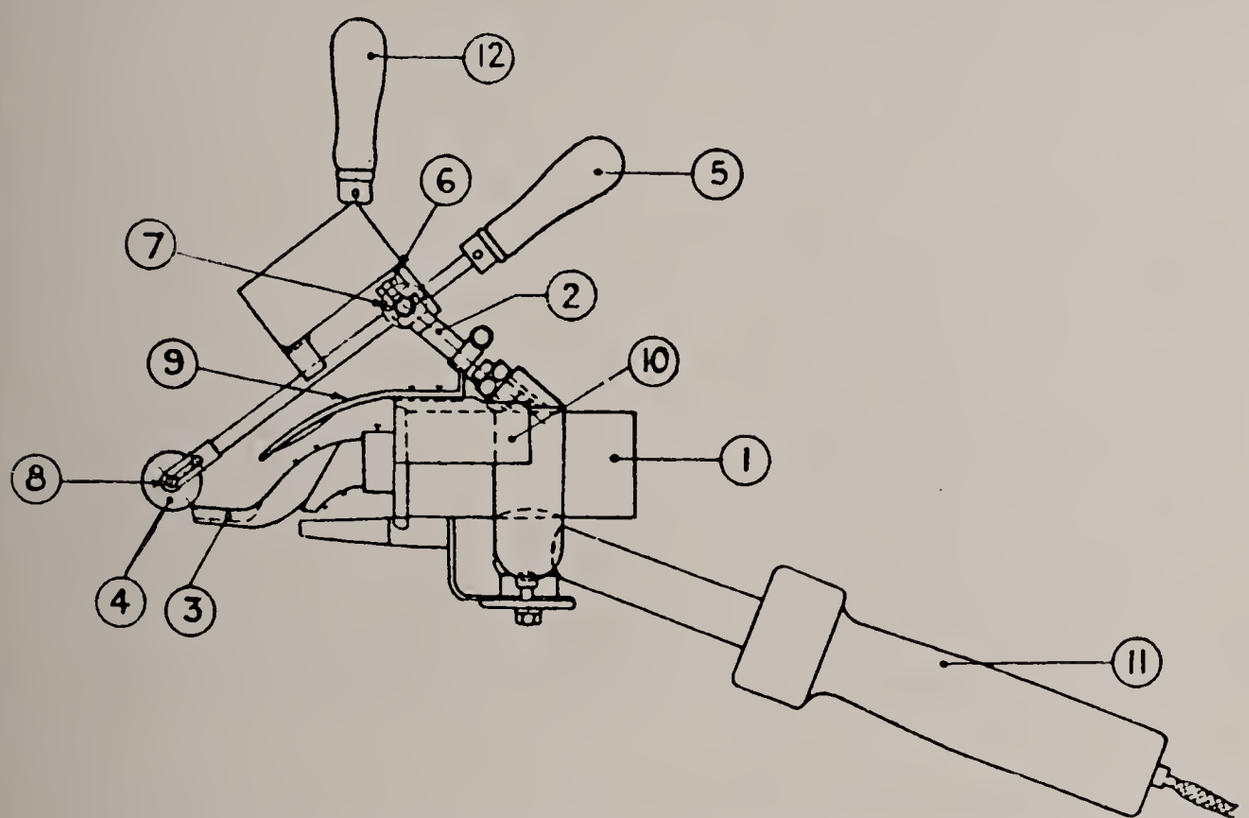

FIG. VIII/4.—Details of the Siebel-Alter machine.

1. Electrically heated soldering iron.
2. Pressure rollers.
3. Copper tongue.
4. Pressure roller.
5. Auxiliary handle (see 12).
6, 7. Setting screws.
8. Shaft.
9. Protective shield.
10. Cover.
11. Handle.
12. Gripping handle.

The Pfaff welding machine shown in Figs. VIII/5 and VIII/6 can be used for making up garments (protective clothing) from plasticized P.V.C. The sheets to be joined are moved over an electrically heated shoe so that their surfaces soften and melt and they are subsequently welded together by pressure rollers. The welds produced on this machine are reasonably neat and, in general, better than those produced

on electronic 'sewing machines' with roller electrodes. The Pfaff machine is ideally suited for the production of garments on a smaller scale, i.e. where the cost is complicated and expensive electrodes for high frequency welding is not justified.

Automatic welding tools have also been developed for making the joints in P.V.C. floors; details of this equipment are not however available.

FIG. VIII/5.—Pfaff welding machine.

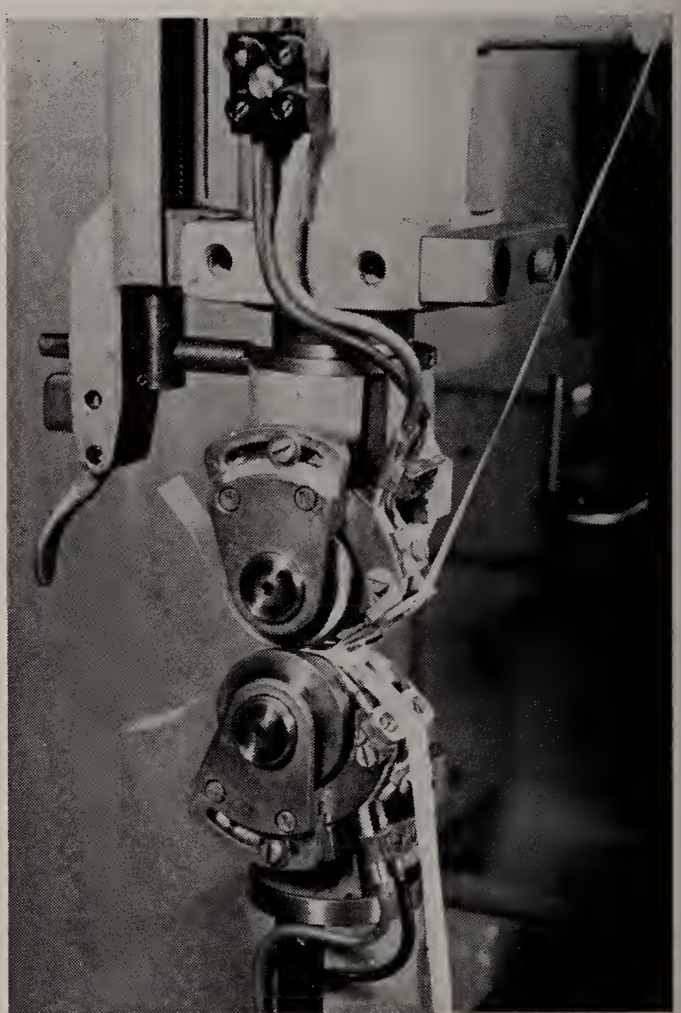

FIG. VIII/6.—Welding head of the Pfaff machine.

High frequency welding

Although most thermoplastic materials are quite good insulators in the ordinary sense, a fact which is borne out by the use of plasticized P.V.C. for cable coverings, etc.; most of them show a considerable power loss if subjected to frequencies of the order of 10 million to 50 million cycles per second.

This power loss, which is called the dielectric loss, shows up as thermal energy, in the material, i.e. a piece of thermoplastic material which is subjected to the influence of a high frequency field heats up very rapidly. High frequency heating was originally exploited for medical purposes and the well known diathermy process makes use of this

phenomenon by subjecting certain parts of the human body to high frequency fields and producing localized heating in those parts.

It was a logical development to introduce this principle of high frequency heating to the welding of thermoplastic materials and this technique, which was originally started in Great Britain in 1941, is now extensively used for the welding of such materials as plasticized P.V.C., cellulose acetate and some others.

For the purposes of welding it is necessary to heat the sheet material and, at the same time, to exert pressure in order to fuse together the heated parts and to consolidate the weld. This is normally achieved by clamping the sheets to be welded between one stationary and one moving metal conductor and by applying high frequency energy to both conductors. At the same time, pressure is exerted and in most cases this pressure can be controlled so that the material is pressed together in the heated state and has the opportunity of cooling under compression.

The early attempts to use a system of metal rollers and to apply the welding current in a point by point method were not entirely successful. Both in the United States and in this country, roller welding machines have been designed but it was found to be extremely difficult to control the high frequency energy in such a way that reasonable welding speeds could be achieved without danger of puncturing the material due to excessive power. It was found much more practical to weld a definite length of material in one operation by using metal electrodes of that length and to continue welding by moving the sheets after each weld and starting the next weld following the finish of the previous one.

These press welding machines are now in commercial use and many articles such as protective clothing, car upholstery, raincoats, etc., are welded from plasticized P.V.C. sheet using the above-mentioned technique.

One advantage of the press welding system can be found in the fact that complicated shapes and quite extensive areas can be welded in a single operation if the welding tools or electrodes are made to follow the desired contour. Naturally the capacity of the high frequency generator has to be sufficient to allow the welding of the area in question. Whilst originally generators with a capacity of a few hundred watts were utilized for this process, it is now common practice to work with high frequency equipment of many kilowatt capacity; the use of presses capable of welding large objects such as seat covers in one operation, has made high frequency welding a practical proposition. Fig. VIII/7 shows a 20 Kw high frequency welder for car panels and seat covers.

One special development of high frequency welding equipment should be described briefly, i.e. the reciprocating bar continuous welding

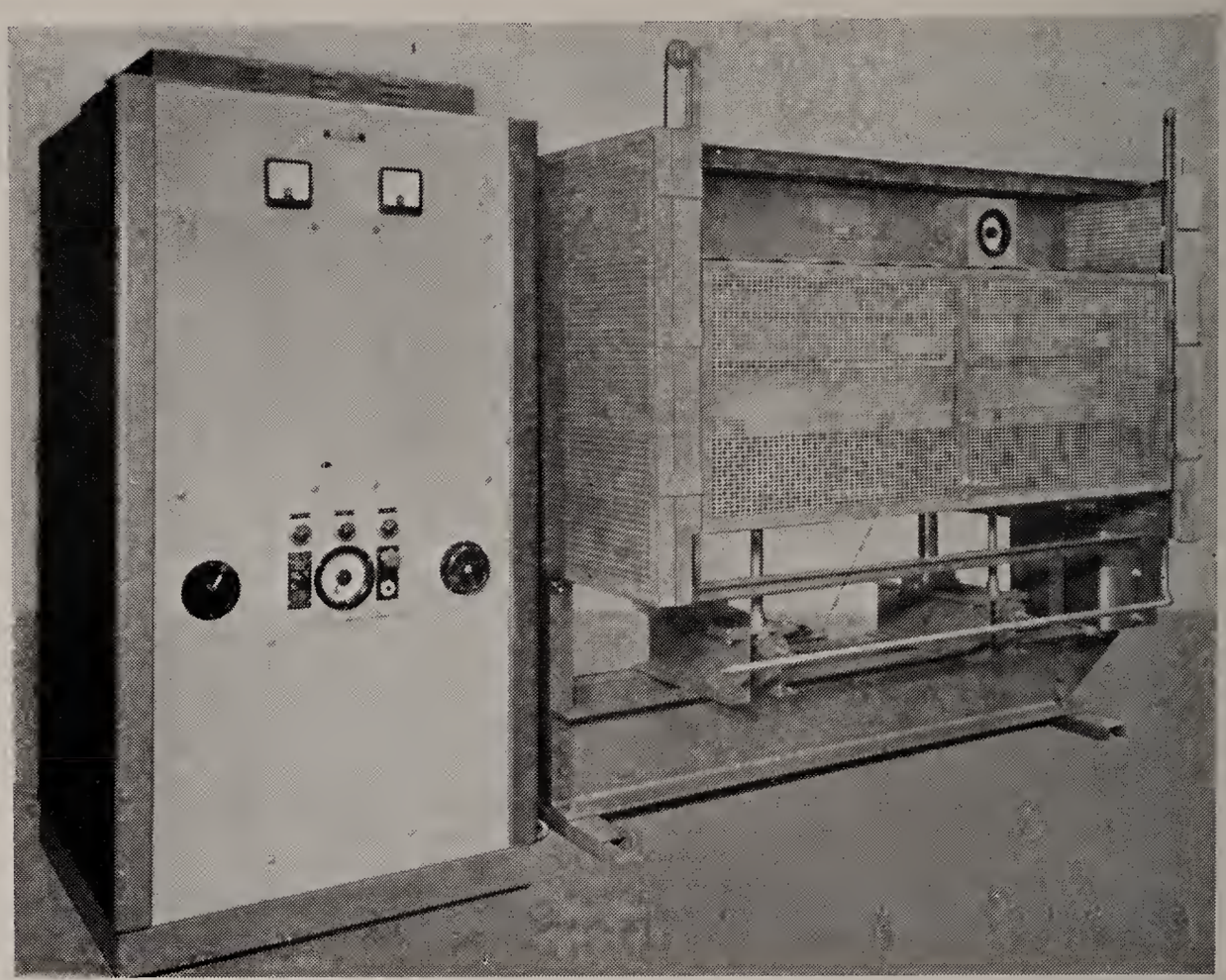

FIG. VIII/7.—20 Kw. high frequency welding press used for the manufacture of door panels and seat covers for cars.

machine. The difficulties encountered with roller welding machines led a number of manufacturers, mostly sewing machine manufacturers, to the development of the so-called reciprocating bar welding machine. In this case the feed of the material is effected by means of pairs of rollers whilst the actual weld takes place between one fixed and one rapidly reciprocating short bar (approximately $\frac{1}{2}$ in. long), so that it is possible to weld contours such as sleeves of protective coats or jackets which show a curvature, in this discontinuous manner by over-lapping individual welds and following a pre-determined path for welding. The garment trade is making use of these reciprocating bar machines which are manufactured by the Singer Sewing Machine Company, the Union Special Machine Company and a number of other firms.

It may be of interest to give a brief explanation of the high frequency welding process and its suitability for various materials. Without going into theoretical details it can be stated that the 'dielectric loss' induced in a plastic material depends on the applied voltage or field strength, on the dielectric constant and loss angle, both of which are physical properties of the material in question, and on the applied frequency. It will be seen immediately that plastic materials with a very low dielectric loss angle are not suitable for high frequency

welding unless a very much higher frequency can be used. Increase in frequency beyond approximately one hundred million cycles per second is not a practical proposition and this is the reason why materials such as polythene, polystyrene and polytetrafluorethylene cannot be welded with ordinary high frequency welding equipment.

The dielectric loss is largely influenced by the plasticizer content and the type of plasticizer used in a particular thermoplastic material. Although it is possible to weld by high frequency, rigid (entirely unplasticized) P.V.C., this requires considerably higher voltages than the welding of plasticized P.V.C. sheeting. The dielectric loss angle is also somewhat dependent on temperature and for this reason it will be found that on ordinary commercial high frequency welding machines, the power required for a certain job can usually be reduced after a certain time of operation. The explanation for this is the following: passage of high frequency current through the electrodes results in some heating of the electrodes and the increased temperature transmitted to the sheets to be welded increases through specific power loss, hence it is possible to use lower powers for welding after this initial heating-up period.

In some instances even, pre-heating of the electrodes has been used to obtain satisfactory welds in materials which are difficult to handle.

As pointed out already the maximum frequency which can be applied cannot be increased at will. On the other hand, it is not possible to increase the power simply by increasing the applied voltage because plastic materials have a definite electrical breakdown strength which must not be exceeded or even approached. If the voltage is increased to such an extent that breakdown or rupture takes place, the material burns and chars but no high frequency heating and therefore no welding, would take place.

High frequency welding is of comparatively recent origin but it has found such widespread applications in so many industries that it can certainly be considered as one of the important technical achievements in the working of thermoplastics.

The theoretical aspects of high frequency welding are much more fully dealt with in *The Welding of Plastics* by Haim & Zade (*3*).

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CHAPTER IX

DETAILED INFORMATION RELATING TO THE HOT-GAS WELDING OF POLYVINYL CHLORIDE

Basic principles of the method

The hot-air method of welding polyvinyl chloride resembles to a certain extent the gas welding process for metals; the use of an open flame for the softening and melting of the material is, however, ruled out, on account of the thermal instability of P.V.C. which blisters and decomposes as temperatures around 200° C. (392° F.).

Henning and Reinhardt, the inventors of the hot-air method proposed the use of hot air, produced by passing compressed air through a stainless steel heater coil or over an electrically heated element for softening both filler rod and parent material, applying pressure simultaneously on the filler rod. This basic principle is still applied to-day.

The filler rod becomes tacky on its surface when suitably softened and the same applies to the surface of the material to be welded. The tacky surfaces bond together under pressure.

Filler rods

Extruded filler rods should be used whenever possible. There are, however, cases where one has to match a particular type or brand of P.V.C. sheet for which extruded filler rods are not available. In such instances suitable filler rods can be produced from the P.V.C. sheet by milling (*1*). Unplasticized P.V.C. filler rods should be used for applications requiring the highest chemical resistance; slightly plasticized filler rods should be confined to work of lesser importance.

The chemical composition of a P.V.C. filler rod has also some influence on the strength of the welded joint. This was already reported by Henning (*2*) who investigated filler rods containing plasticizers (10–50 per cent.). According to Henning filler rods with a plasticizer content of 10 per cent. yielded better mechanical properties than rods of any other composition under test. This type of filler rod was also outstanding as far as weldability was concerned. It became established practice to use slightly plasticized filler rods and rods of German origin contain even to-day 10 per cent. of plasticizers; filler rods entirely free from plasticizers are, however, available on request.

Peukert (*3*) studied a range of filler rods some of which contained

varying amount of plasticizer (T.C.P.). Thermal treatment of these rods at 270° F. (115° C.) resulted in shrinkage which amounted to approximately 2 per cent for completely unplasticized rods; shrinkage increased gradually with increasing plasticizer content and reached a maximum of 7·5 per cent. with a plasticizer content of 20 per cent.

Further tests by Peukert established that the ultimate tensile strength of welds with these rods increased with increased plasticizer content reaching a peak when the plasticizer content was 11 per cent. and decreased slightly thereafter. The first series of tests was broken at room temperature. Tests made at higher temperatures indicated a definite change in behaviour; it was conclusively proved that welds made with completely unplasticized filler rods gave higher values than any other composition under test at 104° F. (40° C.).

Comprehensive tests made under strictly controlled conditions, using an automatic welding machine to eliminate variations in feeding-pressure, welding temperature, etc., confirmed earlier findings. The weld factor of joints produced with plasticized filler rods decreased rapidly with increasing temperature and fell below the lowest permissible value of 60 per cent. at 120° F. (50° C.). On the other hand there was a gradual increase of the weld factor at increased test temperatures when completely unplasticized filler rods were used. (85 per cent. at 68° F.; 86 per cent at 104° F.; 90 per cent. at 140° F.; 100 per cent. at 176° F.).

Filler rods containing plasticizers char easily at higher temperatures, where completely unplasticized rods still behave satisfactorily.

$\frac{1}{8}$ in. filler rods will be found suitable for most applications. The first run of a single-V or double-V butt weld is, however, often deposited with a $\frac{3}{32}$ in. filler rod to be followed by rods of larger diameter. A $\frac{5}{32}$ in. thick filler rod is the heaviest type of rod used for manual welding as the use of rods heavier than this causes excessive strain to the welder's hand. $\frac{1}{4}$ in. filler rods and triangular filler rods are used for semi-automatic or automatic welding. The application of filler rods of substantial cross section eliminates multi-layer welds to a certain degree and results in better mechanical properties of the joint.

The tip of the filler rod should be bevelled at an angle of approximately 30° with a heated knife which can be attached to the tip of the torch. The use of bevelled filler rods facilitates bonding to the surface of the parent material—filler rods with tips square cut have a tendency to lift at the starting point of a weld. (Fig. IX/2 and Fig. IX/3.) It is general practice to cut the filler rod according to the length of a particular run to eliminate joints in a run as far as possible—i.e. to buy filler rods in continuous length (coil) and to avoid rods cut to a specific length by the manufacturer. This may not be practicable, however, in the case of very long seams and several rods may have to be used to execute a full run. The starting of each of these may be a potential

source of trouble unless great care is taken. The proper procedure for joining a new filler rod to a previous run is mentioned on page 93.

Defective filler rods

Defective filler rods are nowadays less frequently encountered as most manufacturers of rods are aware of the causes leading to trouble and they are thus able to cure them without delay. Various factors are known which make a P.V.C. filler rod unsuitable—it may contain air bubbles or voids, it may also have been stretched excessively on the haul-off gear during extrusion. It is not always possible to recognize a defective filler rod at once although experienced welders can, in general, evaluate the behaviour of a rod not only by welding but also by bending or nicking it.

Cutting through a filler rod does not reveal air bubbles or voids in every case as these are occurring at irregular intervals and may be missed. The best way of ascertaining whether the filler rod is at fault is by depositing a multi-layer weld. The second or third layer laid down without delay, i.e. without waiting for the previous runs to cool, will definitely produce a porous weld if the filler rod contains air bubbles.

Preparations

A few preliminary steps are necessary before commencing with the welding operation proper. The P.V.C. sections or sheets to be welded should be clamped firmly to the welding bench or, in the case of larger structures, to the heaviest section, to prevent movement of the individual pieces during welding. The volume of air passing through the torch should be checked by means of a flowmeter and should, if necessary, be adjusted to yield a steady stream of welding gas (15–30 l/min.). The temperature of the welding gas should likewise be checked either by hand (see fig. VII/9) or with a thermometer (to read 280° C.—$\frac{1}{4}$ in. away from the tip of the torch).

The spot on which a weld will be started should now be preheated by directing the stream of hot air from the torch against it and carrying out a circular movement with the tip of the torch. Preheating should be continued for a few seconds until the material changes its colour slightly and its surface becomes glossy. Soon afterwards very fine gas bubbles will appear on the preheated surface—a sign that the material is now ready for welding.

The welding process

It is rather difficult to describe the individual operations carried out during the welding of rigid P.V.C. Prospective welders would be well advised to take part in one of the welding courses nowadays offered by companies manufacturing materials or welding equipment. Training courses are also held by Technical Colleges and Institutes (see

Chapter XVII). A good deal of trouble can be avoided and a lot of time can be saved by attending one of these courses.

Fig. IX/1 to IX/17 can be found between pages 168–169.

Fig. IX/1 to IX/7 show the individual operations involved.

Most welders are right-handed and operate, therefore, the torch with their right hand and feed the filler rod with the left hand (see Fig. IX/1a.) Left-handed operators reverse this procedure.

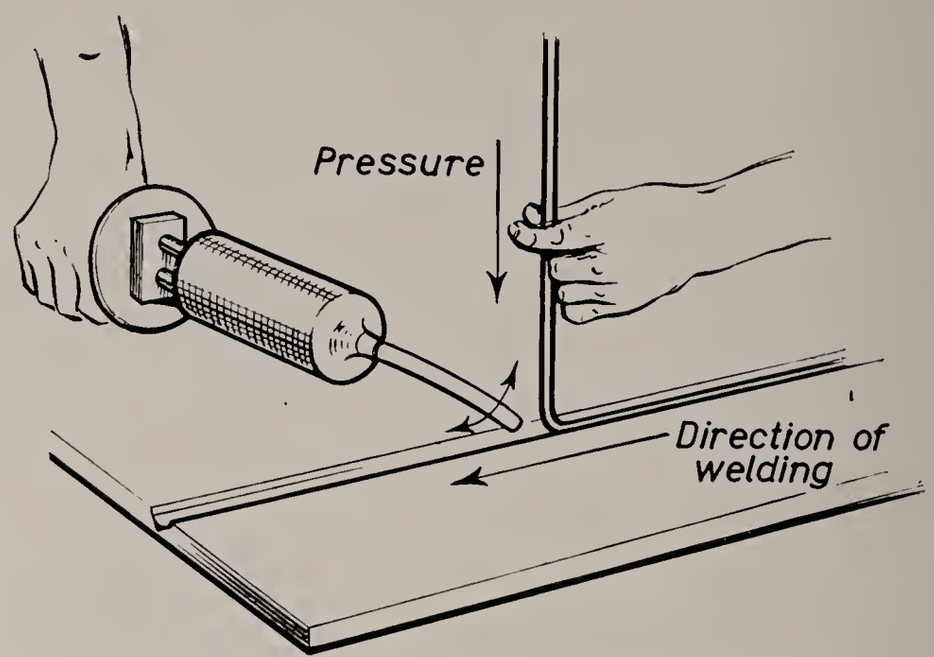


Fig. IX/1a.—Torch welding with feeding of filler rod.

The filler rod should be held between the thumb and the third finger of the left hand, with the thumb approximately 8–10 in. away from the workpiece. (The bevelled tip of the rod should just touch the preheated spot on the workpiece or should be placed into the gap prepared by chamfering.) The welder now starts to perform a slight weaving motion with the torch—so that the tip of the torch moves from 6 o'clock to 9 o'clock and back to 6 o'clock, etc., at an approximate rate of 2–3 weaving motions per second.

The filler rod softens under the influence of heat (from the welding gas) and becomes soft and pliable. It will bend under an angle of 90° towards the horizontal plane and the filler rod still held perpendicularly will proceed from left to right or towards the welder (according to the position) at the rate of 5–10 in. per minute (Fig. IX/4). Uniform pressure should be applied to the rod, to make it flow at a uniform rate, whilst the jet of hot air is alternatively played against filler rod and parent material. The actual pressure to be applied depends on the diameter of the filler rod—smaller rods require less pressure than thicker ones. The following figures are given for guidance:—

$\frac{3}{32}$ in. filler rod	2 lb.
$\frac{1}{8}$ in. filler rod	4 lb.
$\frac{3}{16}$ in. filler rod	7 lb.

It is rather difficult to measure this pressure in practice but for the purpose of training this may be done by placing the object to be welded on a pair of scales which are then properly balanced. Appropriate weights are then placed on the scales (for instance, 2 lb. for tests with $\frac{3}{32}$ in. filler rods). Welding is now carried out with sufficient pressure applied on the filler rod to keep the scales in balance. To apply a pressure of 7 lb. at a uniform rate over a prolonged period is difficult and requires a good deal of practice.

Excessive heating of the filler rod will soften it to such an extent that it will be impossible to apply pressure at the rates indicated. Lack of pressure causes the filler rod to remain on the surface without proper penetration or bonding.

If the temperature of the welding gas and the pressure on the filler rod are properly adjusted, the softened material (from the filler rod) will become visible in the form of a small bow wave at the point where the filler rod turns 90° (see Fig. IX/6). Part of the softened material will exude along the deposit, forming two small waves, one on each side of the deposited filler rod (Fig. IX/5). Absence of these two waves and of the bow wave indicates insufficient bonding caused by insufficient pressure or temperature or both (see Fig. IX/7).

Excessive heat causes carbonization on the surface of the filler rod and the parent material. A certain amount of charred (burned) material will, however, always be formed at the root of the weld and along the two side waves mentioned previously. All burned material should be removed carefully by means of hooks or scrapers before further runs are deposited on top of the previous welds. These hooks or scrapers should have rounded points as sharp hooks may scratch the material and cause notches.

The last two inches or so of a filler rod cannot be used for obvious reasons; they are left standing up for a few seconds to allow consolidation of the weld and are then cut off with a hot knife.

Continuing a run

There are cases where more than one filler rod is required to make a particular run. The correct procedure in such a case is to cut the nearer end of the previous weld at an angle of 45° with a hot knife and to make a fresh start with a new filler rod approximately $\frac{1}{2}$ in. back and welding over the cut end of the previous run. This will result in a little hump at each new start and in a somewhat uneven surface in a multi-layer weld. These humps should finally be removed by scraping or filing. Each new start is a potential source of trouble and should be checked with a high frequency spark tester.

Positional welding

Welding in the overhead position as well as welding vertically down is also possible.

Stretching

Excessive stretching of the filler rod caused by feeding it at an oblique angle (i.e. deviating from 90°) causes transverse cracks in the deposit during cooling. This becomes particularly noticeable in the case of multi-layer welds. A short explanation of the causes of this phenomenon may help to avoid this fault.

The filler rod becomes soft and plastic under the influence of heat and pressure; at the same time it expands approximately 1·5 per cent. in length when heated from ambient temperature to approx. 380° F. It will contract to the same extent on cooling to room temperature. Measuring a given length of filler rod before and after deposition reveals, however, that the filler rod has increased considerably in excess of the 1·5 per cent. mentioned above. (Increases in length up to 40 per cent. are quite common with inexperienced welders.) It can therefore be assumed that the filler rod has been stretched during deposition and it can be proved by experiments that feeding of the filler rod at an oblique angle increases stretching whilst it can be almost eliminated by giving the filler rod a slight forward slope during feeding. The stresses caused by excessive stretching are responsible for these transverse cracks—reducing the stretching to a bare minimum will eliminate them entirely. A certain amount of stretching (up to 15 per cent.) is, however, almost unavoidable but harmless. It is rather useful to control the quality of welds from time to time by measuring the amount of 'stretching' practised by individual welders and to draw their attention to the harmfulness of excessive stretching.

Figs. IX/8 and IX/9 illustrate cracks in welds due to excessive stretching.

Visual examination

Experienced welders are able to judge the quality of a P.V.C. weld from its appearance—from the presence or absence of the slight waves on each side of the deposit, from its shape, its regularity, etc. Obvious faults can often be recognized at once. To judge the quality of multi-layer welds by visual inspection is much more difficult, as such superficial examination provides no evidence of the general workmanship or efficiency of a welder, since the first few runs of a multi-layer weld can, for instance, be rather poor in quality whilst the top layers are carefully deposited.

For more careful and thorough examination the preparation of polished cross section of the weld is often useful. This can be prepared by cutting across a weld and the adjoining parent material and subsequent rubbing down of the surface on fine emery paper using

comparatively little pressure. Typical examples of specimens so prepared are shown in Figs. IX/10 to IX/17.

Fig. IX/10, for instance, shows a cross section through a single-V butt-weld. Insufficient heat was applied when making this weld as can be seen from the complete absence of foamed (softened) material at the root and around the circumference of the individual layers, which are still truly circular. The two side-waves are also missing. A tensile test would yield low values due to insufficient bonding.

Fig. IX/11 refers to a weld executed with excessive heat. Part of the material was charred and some of the carbonized matter can still be seen between the individual layers. Low tensile values would be found.

Fig. IX/12 reveals voids at the root of the weld due to insufficient penetration. Such voids act as notches when the weld is stressed under tension or impact and reduce the mechanical properties of the weld to a considerable extent.

Fig. IX/13 illustrates a cross-section through a multi-layer weld deposited by using a variety of filler rods of different colour. This procedure would obviously not be considered in practice but is rather useful for the purpose of teaching trainee welders.

Figs. IX/14 and IX/15 show cross-sections through a single and a double-V butt-weld produced under proper working conditions. The edges of the sheets chamfered under an angle of 60° are no longer straight—they have become distorted due to the penetration of the filler rod. Penetration at the root is satisfactory and there are no signs of charred material. Tensile tests on both these welds yield high values.

Figs. IX/16 and IX/17 refer to cross-sections through lap-welds, corner-welds and fillet-welds.

Mechanical testing

Visual inspection of a weld gives little indication concerning the actual strength of a joint and one has to resort to a proper tensile test on a tensile machine whenever this is required.

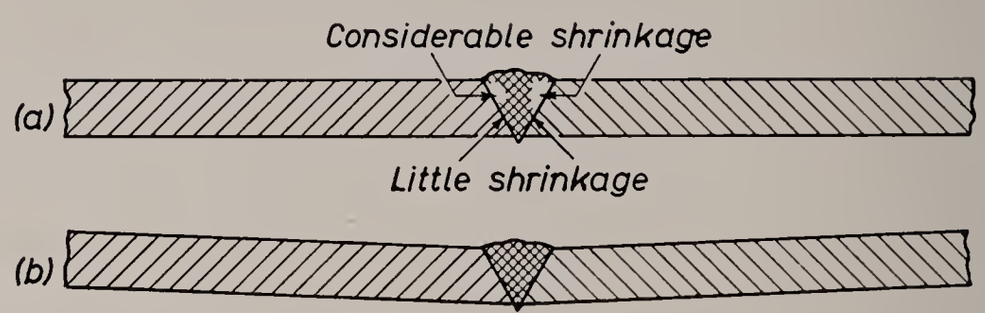
For this purpose sample welds are deposited into the chamfered groove between two P.V.C. sheets of suitable size; at least four specimens, each 12 in. long by 2 in., are cut out from the centre portion of the sample—the start and the finish of the weld are discarded. The specimens are then left for 24 hours to consolidate and to acquire the temperature of the room; this also allows residual stresses to reach their final distribution. Testing is carried out at a straining rate of 1 in. per minute. It is advisable to leave the welds undressed.

The ratio of the tensile strength of a welded joint to the tensile strength of the parent material given in per cents. is usually quoted as weld factor, quality factor or weld quality.

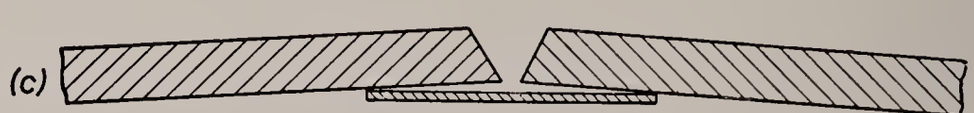
Distortion

Most welded structures are under tension or stress especially if the welds are deposited on one side only (single-V butt-welds). This applies to metal welds and welds in rigid P.V.C. alike.

The actual reasons for distortion are uneven expansion and contraction throughout the weld (see Fig. IX/18). This effect is much more noticeable in rigid P.V.C. welds than in metal-welds due to the relatively high coefficient of expansion and contraction of this material (approximately eight times that of steel); it is also due to the poor heat conductivity of the material.



Distorted welded structure due to heavy shrinkage near to the crown of the weld



Distortion can be prevented by off-setting of the P.V.C. sheets prior to welding.

Undistorted welded structure.

FIG. IX/18.—Distortion of a polyvinyl chloride welded structure caused by unsatisfactory set-up. Proper set-up (shown below) compensates for distortion.

The deposit on the top of a butt-weld contracts considerably more than at the root and causes the sheets to be welded to lift in the upwards direction. It is therefore general practice to offset the sheets prior to welding so that subsequent contractions will straighten them. The amount of offset depends on the thickness of the material and the speed of welding. Similar conditions are encountered in metal welding and in both cases a great deal of experience is necessary to judge how much off set is required.

Dressing of welds

It is general practice to leave P.V.C. gas welds as deposited, i.e. not to dress them, unless a perfectly flat surface is required, for instance, on the inner side of a flange. Dressing removes part of the weld and also causes surface notches which may reduce the mechanical properties of the joint; welders may become careless when dressing of the welds is permitted, as untidy and unsatisfactory welds can be 'beautified' by this treatment.

Repairs

All charred or burned material has to be removed with a suitable tool. The same applies to sections of the weld containing cracks, fissures or voids. It is rather pointless to overweld such faults as these represent notches and will open up under stress. Great care should be taken to remove the entire length of a faulty section and to reweld afterwards.

Testing of welders

The testing of arc welders is a regular procedure in shipyards, boiler-maker shops and other factories producing steel work of major importance. Tensile tests, bend tests and X-ray investigations are carried out to control the work. Failure to pass these tests results in the removal of the particular welder from this type of work until he requalifies by subsequent tests.

Testing of plastic welders is not yet a standard procedure—but some shops have already recognized the necessity of improving the work of their welders and have started on regular tests with gratifying results. Wide variations in efficiency—from 25–85 per cent. are not uncommon—but this divergency in results is soon remedied once regular check tests are introduced; efficiencies exceeding 60 per cent. should be achieved by all welders on rigid P.V.C. work.

Hot-air welding of plasticized P.V.C.

The procedure for hot-air welding of plasticized P.V.C. is slightly different from the technique used for rigid P.V.C.

Filler rods

Plasticized P.V.C. filler rods or strips are rather soft and cannot be fed in the same way as rigid, unplasticized P.V.C. rods. The technique of feeding this type of filler rod is somewhat similar to that used for polythene; quite often follow-up rollers are employed to press the softened deposit firmly into the grooves and corners. Triangular filler rods are preferred to round filler rods as they fill a Vee-groove easily in one run thus eliminating multiple runs. Rigid, unplasticized filler rods can be used in cases where plasticized filler rods are not available.

Types of welds used for jointing plasticized P.V.C.

The most satisfactory joint for plasticized P.V.C. is a lap-weld. Fillet-welds, butt-welds and corner-welds are also used but to a lesser extent. In the case of butt-welds preparation of the material (bevelling or grooving) by means of hand routers or special milling tools is preferred to cutting of the edges by means of ordinary knives, as any irregularities in the preparation of the edges can be noticed afterwards on the welds. Home-made gouging tools are often used for the preparation of V-joints. A soldering iron with a special tool bit attached is brought to a temperature of approximately 350° C. and passed over the abutting edges which require joining. The hot bit of the soldering iron penetrates very quickly into the P.V.C. sheets and prepares a V-groove when it is drawn along. The burnt material has to be removed afterwards as it would prevent proper bonding.

Welding tools

Torches used are either of the gas-heated or of the electrically-heated type with a flattened nozzle attached; better results are obtained with hydrogen torches (see Chapter XIII). All welds made in plasticized P.V.C. should be checked carefully by means of a spark tester to locate pinholes through which corrosive liquids may percolate and destroy the material underneath.

Precautions

Adequate precautions should be taken to remove the fumes resulting from the welding operation. These fumes are unpleasant and cause some discomfort to the welders, but they are not dangerous or poisonous.

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CHAPTER X

TYPES OF WELDS SUITABLE FOR POLYVINYL CHLORIDE

PRACTICALLY all the types of welds known for the welding of metals can be used for the welding of rigid polyvinyl chloride (Fig. X/1). These are:—

Butt-welds
Corner-welds
Edge-welds
Fillet-welds
Lap-welds
Strip-welds

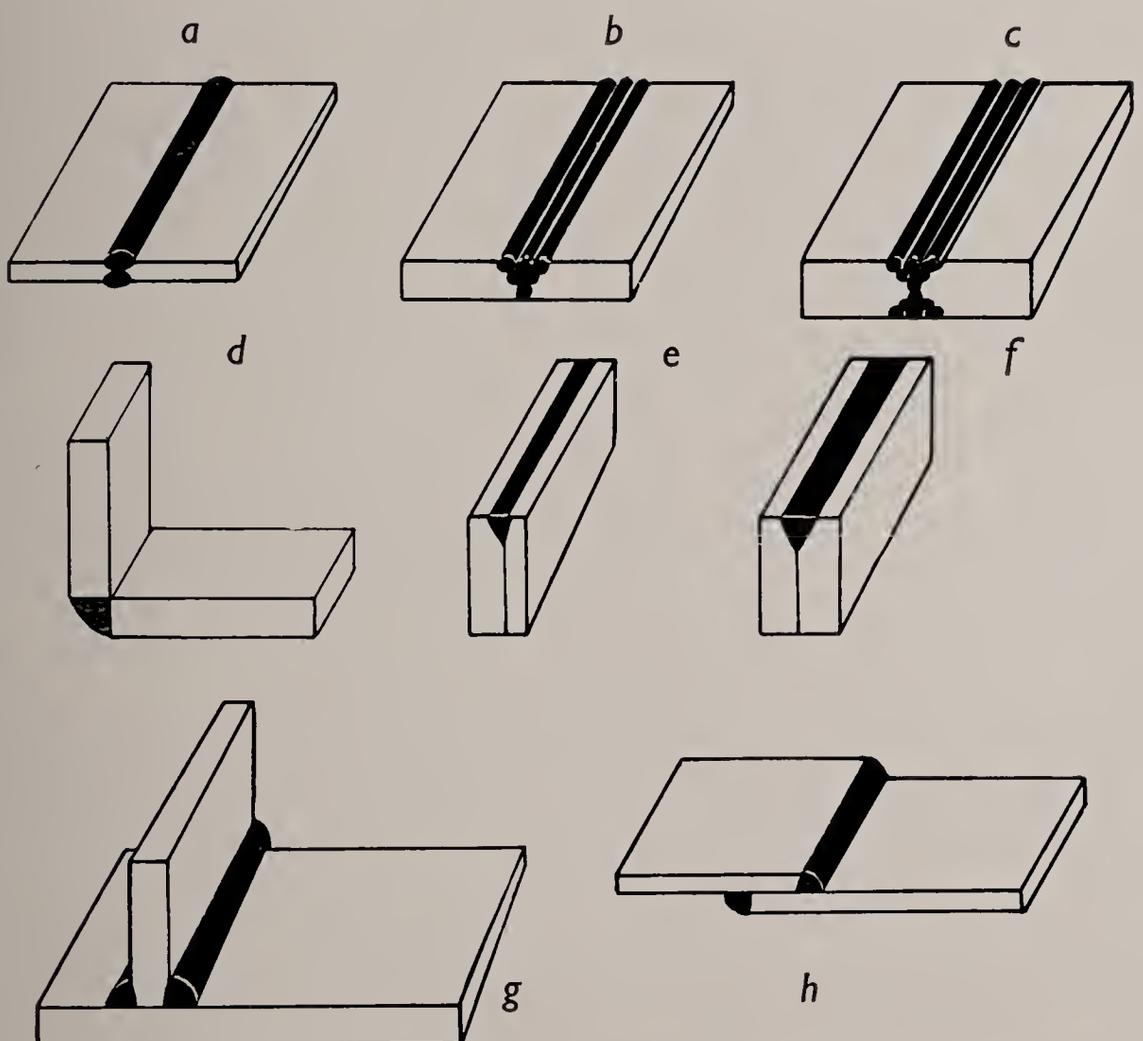

FIG. X/1.—Different types of welds practised in the fabrication of rigid polyvinyl chloride.

(a) Plain butt-weld with sealing run.
(b) Single vee butt-weld, multi layer deposit.
(c) Double vee butt-weld.
(d) Corner-weld (sealing run on inside not shown on illustration).
(e) and (f) Edge-welds.
(g) Fillet-weld.
(h) Lap-welds.

Butt-welds

Butt-welds can be specified as:—

Square butt-welds
Single-V butt-welds
Double-V butt-welds

Square butt-welds are only used for thin sheets ($\frac{1}{16}$ in. thick or under) but in cases where there is very little mechanical stress, sheets up to $\frac{1}{8}$ in. thickness can be joined by an ordinary square butt-weld. A root-gap of $\frac{1}{64}$ in. should be allowed to ensure proper penetration. No preparation is required but clamping of the sheets is advisable to avoid distortion.

Filler rods of $\frac{1}{8}$ in. thickness are used and a sealing run on the reverse side may be applied to strengthen the joint. See Fig. X/1a.

Single-V butt-welds

Single-V butt-welds are employed for thicker sheets ($\frac{1}{8}$ in. or heavier). They are cheaper in production than double-V butt-welds and preferred when the reverse side of the sheet is comparatively inaccessible. Uneven numbers of runs are made, i.e. 3, 5 or 7. The edges of the sheets should be chamfered at an angle of 60° to 75° and roughened as rough surfaces increase the strength of the weld. A root-gap of 0·020 in. to 0·040 in. should be allowed to provide for penetration, see Fig. X/2.

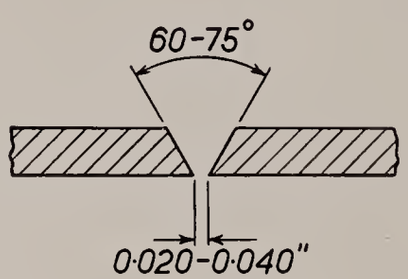

FIG. X/2.—Preparation for single-vee butt-weld.

The first run is always laid with a thinner filler rod, for instance, $\frac{1}{8}$ in., this is followed by further runs in either $\frac{1}{8}$ in. or $\frac{5}{32}$ in. filler rod and a sealing run on the reverse side of the sheet, see Fig. X/3.

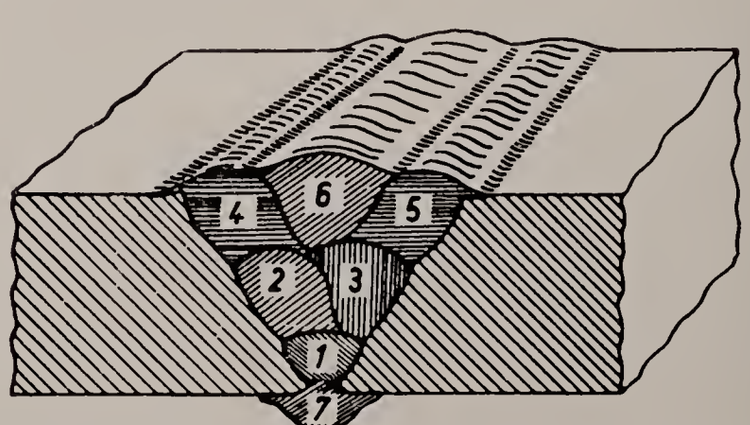

FIG. X/3.—Sequence of runs for single-vee butt-weld with sealing run.

Double-V butt-welds

Double-V butt-welds are stronger than single-V butt-welds but they are also more expensive to make. The edges of the sheets to be joined should be veed-out at an angle of 60° to 75° on each side and a slight gap of 0·020 in. to 0·040 in. should be left in the centre for penetration. See Fig. X/4. Clamping of the sheets is advisable to avoid distortion. Double-V butt-welds are, in general, 10–20 per cent. stronger than any other type of weld in rigid P.V.C.

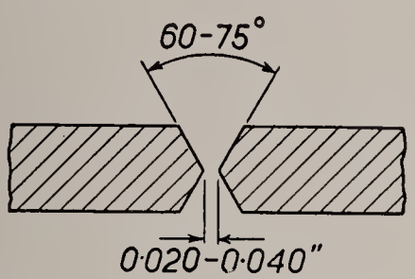

FIG. X/4.—Preparation of sheet for a double-vee butt-weld.

Corner-welds

Corner-welds are used when two sheets are welded together at an angle of 90°. This type of weld should be avoided whenever possible and the design of a particular structure is usually laid out in such a way that corners are provided by bending the sheets and locating the weld away from the corner to make the use of butt-welds possible.

Preparation of the edges is usually not required, but rigid clamping of the sheets or components is necessary especially with heavier sheets. An odd number of runs (1, 3 or 5) is applied and a fillet-weld should be deposited on the inside of the corner to prevent cracking and failure under expansion, see Fig. X/1d.

Failures occur frequently with corner-welds as welders or designers forget about this additional fillet-weld which is unusual in metal welding.

Edge-welds

There are two different types of edge-welds, see Fig. X/1e and X/1f. The first type requires preparation of the sheets, i.e., chamfering at an angle of 60° to 70°, whilst for the second type only one sheet has to be chamfered.

Fillet-welds

Fillet-welds are very often deposited without previous preparation

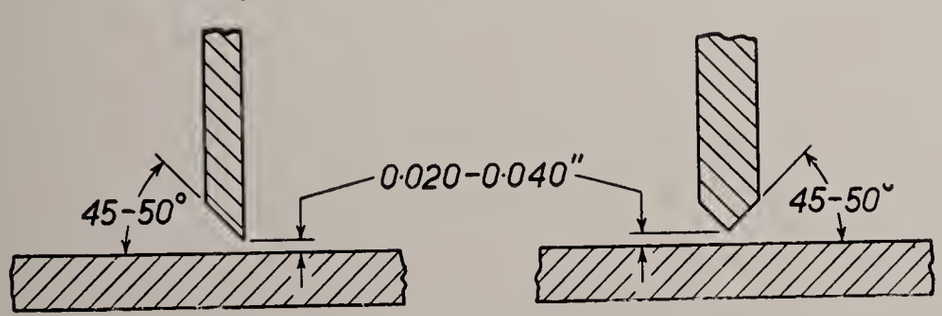

FIG. X/5.—Preparation of sheets for fillet-welds.

of the sheets. It is, however, an advantage to chamfer at least one side of the vertical component; a root gap of 0·020 in. to 0·040 in. is necessary and clamping is recommended, Fig. X/5. Single runs are usually not sufficient and several runs (either 3 or 5) are made.

Lap-welds

Lap-welds are rather weak and should be avoided whenever possible. They are used for the joining of relatively thin sheets. An overlap of at least $\frac{3}{8}$ in. should be provided.

Strip-welds

Strip-welds are used on tank linings in rigid P.V.C. foil or for the welding of plasticized P.V.C.

In the case of rigid P.V.C. foils a single run plain butt-weld is covered by an overlapping strip of P.V.C. approximately $\frac{1}{4}$ in. wide; the strip is cut from the same type of sheet from which the lining has been made. The butt-weld has, of course, to be ground flush before application of the sealing strip and all traces of cement have to be removed as they interfere with the welding.

In the case of plasticized P.V.C. linings a sealing run is made with special strips (flat or profiled) employing a pressure roller to assist bonding, see Fig. X/6.

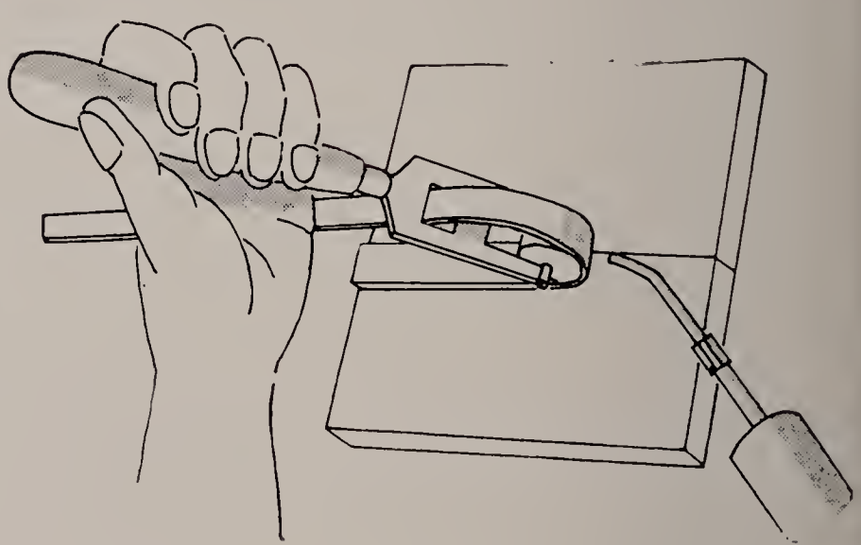

FIG. X/6.—Strip-weld on plasticized P.V.C. using a pressure roller.

Positional welding

In general all the welding of rigid P.V.C. is carried out in the down-hand position and well equipped workshops are using turntables, rollers and the like to enable the welders to work in their most favourable position. Welding in the vertical and overhead position presents no difficulties but it takes longer and causes fatigue to the welder.

Strength of welds

A variety of factors influence the strength of a P.V.C. weld and they are mentioned below in order of importance:

(1) Strength of parent material (sheets, rod, blocks, etc.).
(2) Quality of filler rod.
(3) Temperature of the welding gas.
(4) Pressure exerted on the filler rod.
(5) Speed of welding.
(6) Type of weld.
(7) Preparation of components to be welded (chamfering, roughening of surfaces, clamping, etc.).
(8) The individual skill of the welder.

The strength of the parent material is generally of the same order as that of the filler rod unless the latter is plasticized. The influence of plasticizers, correct heating and speed of welding, on the strength and quality of a weld is discussed on pages 89, 90. Stretching of the filler rod whilst welding causes stresses and may greatly reduce the mechanical properties of a weld, but this depends entirely on the skill of the welder.

Faulty filler rods (of uneven cross-section or containing air or voids) can be another reason for weak welds.

Design considerations

Designers of plant who have not had previous experience in the fabrication and welding of P.V.C. should familiarize themselves with the peculiarities of this material in order to avoid failures and costly experiments.

The relatively low tensile strength of rigid P.V.C. is very often forgotten and chemical plant, especially ducts, are fabricated from sheets which are too thin. Ducts exceeding 18 in. in diameter should be constructed in $\frac{3}{16}$ in. thick material or heavier sheet. The average strength of a weld in rigid P.V.C. can be taken at 60 per cent. compared with that of the parent material; in exceptional cases, where highly skilled welders are employed, better welds can be expected and a quality factor of 80 per cent. can be assumed. Automatic welding may raise this factor still further and a quality factor of up to 100 per cent. of the parent material can be achieved.

The use of heavier filler rods, higher pressures on the filler rod during welding, also yield better and more uniform welds.

Notches are fatal. Unfortunately they are not always visible—for instance, voids in multi-layer welds or charred material not removed, may act in the same way as notches; any undercut along the welded seam also has a notch effect.

Most welds are under stress caused by contraction of the filler rod whilst cooling. The parent material is usually stress-relieved by the manufacturer of the sheet and failures nearly always occur in the welds

at first, although cracks due to notch effects may extend subsequently into the parent material.

The use of filler rods of heavier cross-section and elimination of multi-layer welds is one method of avoiding stresses in welds, and another is to avoid stretching of the filler rod during welding.

The heat conductivity of rigid P.V.C. is low; steel for instance conducts heat approximately 200 times better than P.V.C. Dissipation of heat around a weld is negligible and great care is therefore necessary to avoid overheating or burning.

The expansion or contraction of rigid P.V.C. is approximately seven times greater than that of steel, a fact which has to be remembered in the case of tank linings and also in the erection of pipelines.

The mechanical strength of rigid P.V.C. diminishes rapidly with increasing temperature and this prohibits the use of rigid P.V.C. as a material of construction for applications beyond 150° F. (65° C.) (unless ample external support is provided).

The brittleness of rigid P.V.C. below the freezing point of water 32° F. (0° C.) has also to be taken into consideration. Proper design and avoidance of notches allows its use at somewhat lower temperatures (−40° F. or −20° C.) but this is not considered good practice.

Butt-welds with a sealing run at the root are more satisfactory for constructions which are statically and dynamically stressed and this type of weld should be given preference over corner-welds, lap-welds and fillet-welds whenever possible.

Proper planning a necessity

The proper planning of all the individual operations involved in a fabrication is time-and-labour saving. Such planning is commonly practised in metal fabrications, but has not been widely adopted in the welding and fabrication of rigid P.V.C.

How proper planning can improve production methods was discussed by Krekeler (*1*) at a conference held at Aachen in 1950. Krekeler pointed out that there were at least six points to be considered in such planning. Schedules relating to the actual welding work and all further work involved as well as schedules for labour, plant and material, should be prepared and co-ordinated. Krekeler gave practical examples, one of which is quoted below. This refers to the fabrication of the nitrous oxide absorption plant, illustrated in Fig. XVI/20.

Angular brackets, such as the one shown in Fig. X/7 are in frequent use on this plant. There are several ways of welding up this bracket, but Fig. X/8 shows the preferred sequence of welding operations. The two outer welds (1 and 2) should be deposited first, to be followed by the two inner welds (3 and 4). The sequence for the remainder of the welds is also given. The outer welds are only stressed in compres-

sion and may be dressed to give a smooth surface. The individual brackets are finally welded to the shell of the absorption tower.

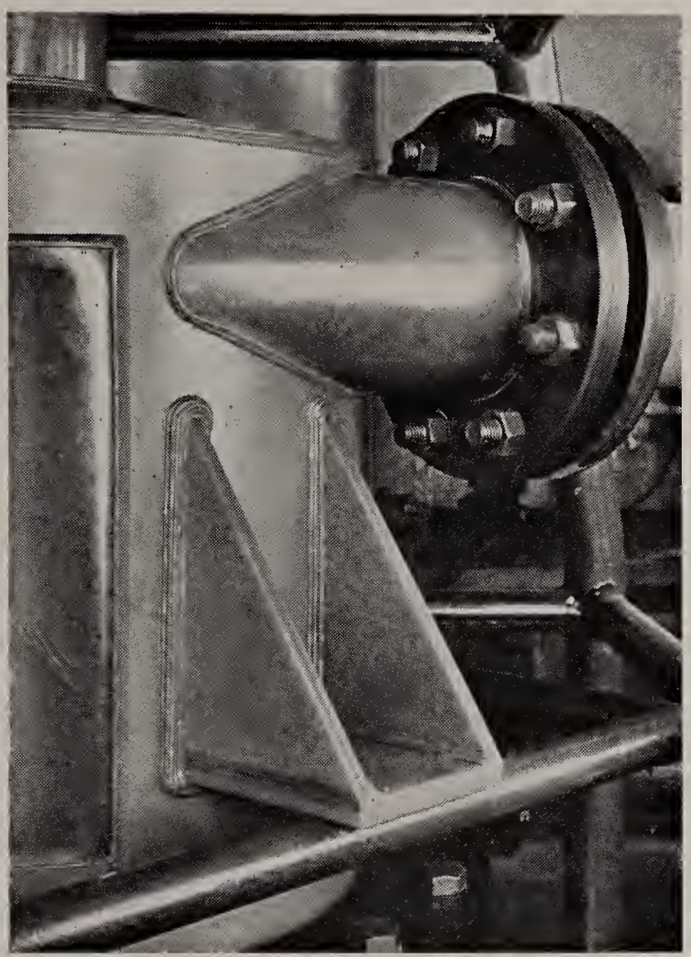

FIG. X/7.—Polyvinyl chloride bracket. The proper sequence of welding is shown in Fig. X/8.

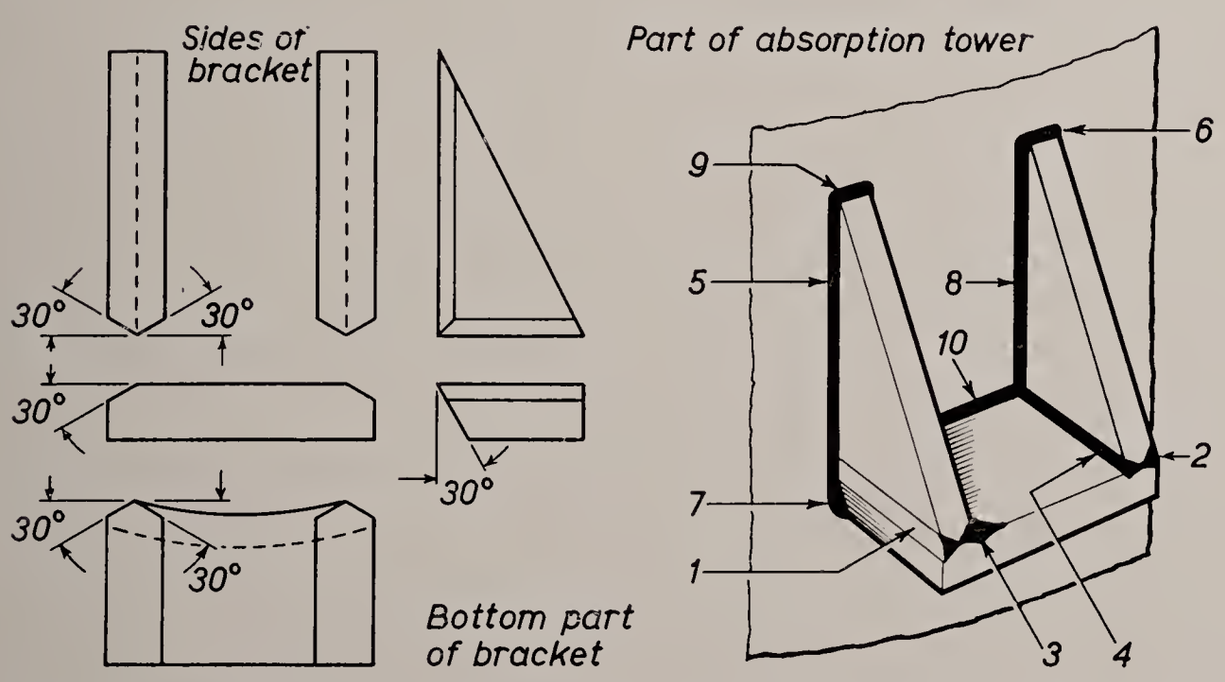

FIG. X/8.—Sequence of welding operations for a P.V.C. bracket forming part of an absorption tower.

The proper assessment of the individual times to be taken for each operation is a most difficult task, requiring a good deal of experience. German factories use tables, originally prepared by a committee of engineers and practical men from the Plastic Fabrication Workshops of the various factories of the I.G. Farbenindustrie concern at Leuna, Bitterfeld, Ludwigshafen, Leverkusen and others.

REFERENCE

1. Anon.
'P.V.C. Welding Operation', *British Plastics*, Vol. 24, (1951), No. 261, (February), pp. 44–45.

RECOMMENDED LITERATURE

Voigt, P., 'Schweisstechnische Gesichtspunkte für die Gestaltung von Kunststoff-Konstruktionen', *Industrie-Anzeiger*, Vol. 76, (1954), No. 90, (November), pp. 1395–1399.

CHAPTER XI

EQUIPMENT USED IN A WORKSHOP FOR THE FABRICATION OF POLYVINYL CHLORIDE

It has to be realized that the fabrication of rigid polyvinyl chloride is, in general, carried out on a reasonably small scale; even the largest fabrication shops of this kind employ less than 100 men. Very often a P.V.C. fabrication shop is started off as a side line by factories or workshops already dealing with metals. Manufacturers of ventilation equipment, for instance, branch out into new fields and an obvious addition to their activities is the manufacture of plastic duct lines and fans.

Chemical manufacturers will become interested in the lining of tanks and plumbers may take up plastic plumbing to remain competitive with other firms who already instal plastic pipes.

A considerable amount of equipment may, therefore, already be available and only tools and equipment specifically suited for the fabrication and working of polyvinyl chloride may have to be obtained.

Apart from actual welding equipment, which is described in Chapter VII, very little is therefore needed in the earlier stages. Later, when the activities of a plastic workshop are extended, some more complicated and more expensive equipment will be required. Their choice depends on the manufacturing methods to be adopted and the capital available. The machines and equipment mentioned below are dealt with in the order of their importance.

Preheating ovens

A preheating oven is essential for the manufacture of large bore tubing from rigid P.V.C. sheet. Smaller ovens are obviously cheaper than large ones but fabricators are well advised to consider the purchase of an oven sufficiently large to allow for the preheating of large sheets. The oven shown in Fig. XI/1 has forced draught air circulation and is thermostatically controlled for temperatures up to 480° F. (250° C.).

Shelves are provided to allow for the simultaneous preheating of up to six sheets 6 ft. long × 4 ft. wide; flaps are also provided to prevent heat losses in the individual sections in the oven, once the doors are opened.

Power Requirements: Approximately 3 Kw.

FIG. XI/1.—Preheating oven with forced air circulation and thermostatic control.

Preheating tables

Some workshops prefer to preheat P.V.C. sheet or foil on steam heated tables instead of in preheating ovens. Such preheating tables can be obtained at reasonable prices from manufacturers of pressing equipment for laundries and dry cleaners, but they may have to be modified to make them suitable for higher temperatures and pressures equivalent to 260–280° F. (125–140° C.). Preheating tables have the advantage that the material cannot be overheated, as may happen in a preheating oven when the temperature controls are accidentally set higher than required.

Bending tables

It is bad practice to employ corner welds in the fabrication of rigid P.V.C. and whenever possible corners should be produced by bending. Comparatively short pieces can be bent after preheating of part of the P.V.C. sheet over an open flame, but such corners are not very accurate as the preheated area is relatively large. The use of bending machines with infra-red or electric heaters and proper tilting arrangements is recommended. Fig. XI/2 shows a bending machine with a special form tool which allows the arbor or bending bar to be taken out and to be exchanged for other bars of different shape. The four corners of the bending bar have different radii to suit various

thicknesses of sheet. The bending bar of such bending machines should be pivoted to allow for the withdrawal of the section after bending.

Power requirements: Approximately 1 Kw.

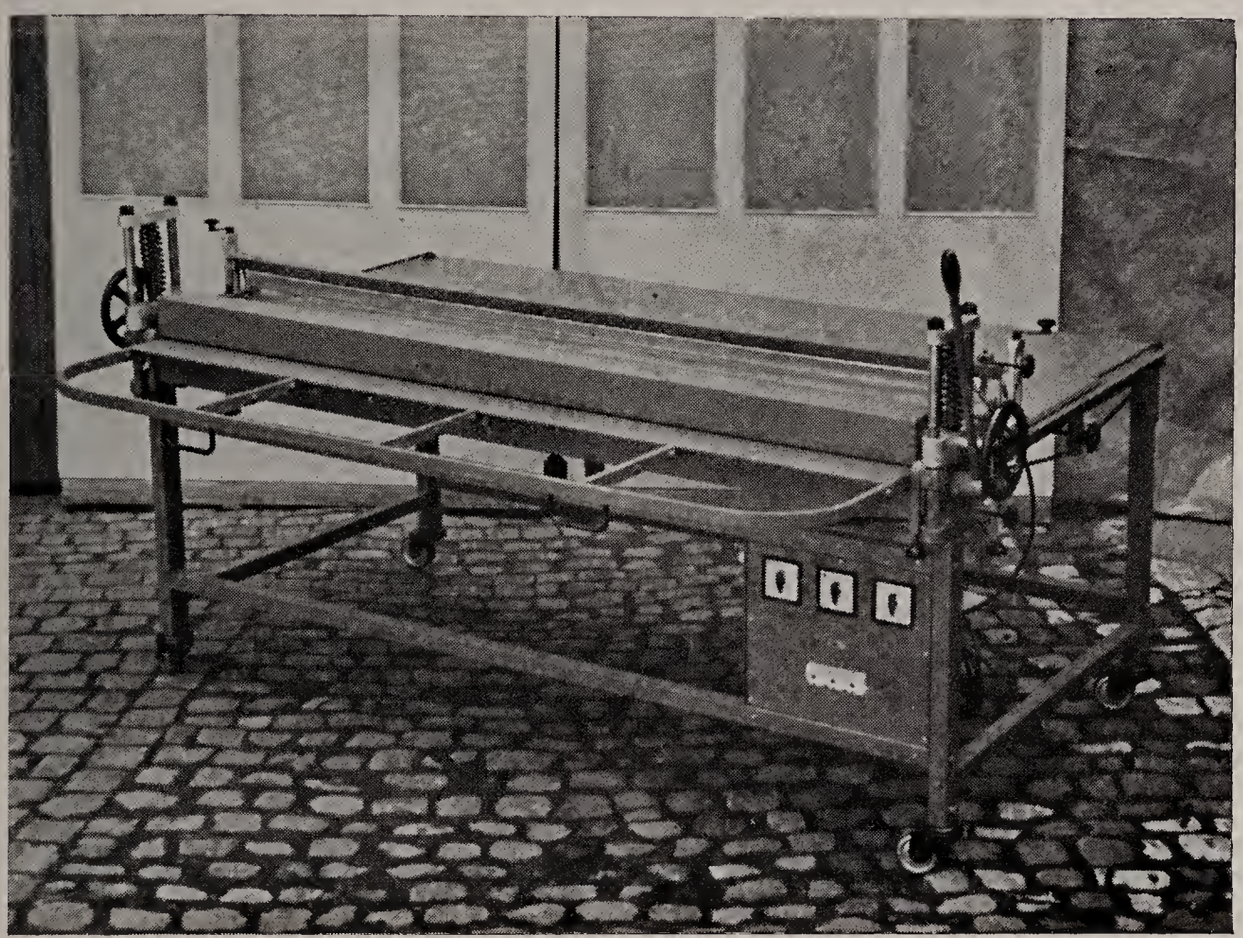

FIG. XI/2.—Machine for bending polyvinyl chloride sheet incorporating infra-red heaters.

Pipe bending machines

German P.V.C. fabricators use specially built bending machines for bending P.V.C. pipes up to 4 in. in diameter (*1*, *2*). These machines are, however, rather expensive and not very economical in use. Readers are referred to the original literature describing this equipment.

Assembly table

An assembly table with a perfectly flat surface is used with great advantage for the assembly of P.V.C. ducts or pipe lines. Such a table can be constructed quite easily from bricks and concrete. Four or six brick pillars are covered with a cast concrete top, approximately 10 ft. long $\times$ 6 ft. wide, and at least 4 in. thick. This concrete top should be rendered subsequently with a layer of fine cement or mortar ($\frac{1}{2}$ in. to 1 in. thick) to make it level over its entire surface. The height of this table should be approximately 3 ft. from the floor.

Deep drawing equipment

There are many cases where a fabricator may have to produce a large number of parts of complex shape from P.V.C. sheet or foil. To weld these up from individually cut sections may be too expensive, neither would the accuracy of the articles so produced be sufficient to allow for interchanging on an assembly line. In such cases advantage can be taken of deep drawing by means of air operated or hydraulically operated presses.

An air-operated press is usually cheaper than a hydraulic one, but there are limitations in regard to size and pressure. Fig. XI/3 shows a press operated by two air cylinders with the loading table withdrawn. Types of work which can be carried out on such equipment are scoops, pump parts, housings for fans of smaller size, photographic dishes and the like.

FIG. XI/3.—Air-operated press for deep drawing rigid polyvinyl chloride sheet.

Wooden forms (male and female) are employed. The thickness of the P.V.C. sheet that can be formed on such a press varies from $\frac{1}{32}$ in. to $\frac{1}{4}$ in. and may go up, in exceptional cases, to $\frac{3}{8}$ in.

Power requirements: Approximately 5 h.p. (on the compressor).

Vacuum drawing is preferred to deep drawing for articles made from P.V.C. foil and sheet not exceeding $\frac{3}{8}$ in. in thickness.

Most vacuum machines are self-contained, i.e. they have built-in infra-red heaters and vacuum pumps.

Typical examples of vacuum forming are P.V.C. boxes, trays, developing dishes, name plates, sign boards and the like. Vacuum forming is, in general, a more economical proposition because of the higher speeds and lower costs of material; the moulds, too, are cheaper than those required for deep drawing.

Power requirements: Approximately 2 Kw.

Motor-driven circular saws

These should preferably be of the tilting arbor type and should be of sufficient size to allow for the use of saw blades up to 12 in. diameter; useful additional accessories include an auto-set mitre gauge, see fig. XI/4.

Power requirements: Approximately 1 h.p.

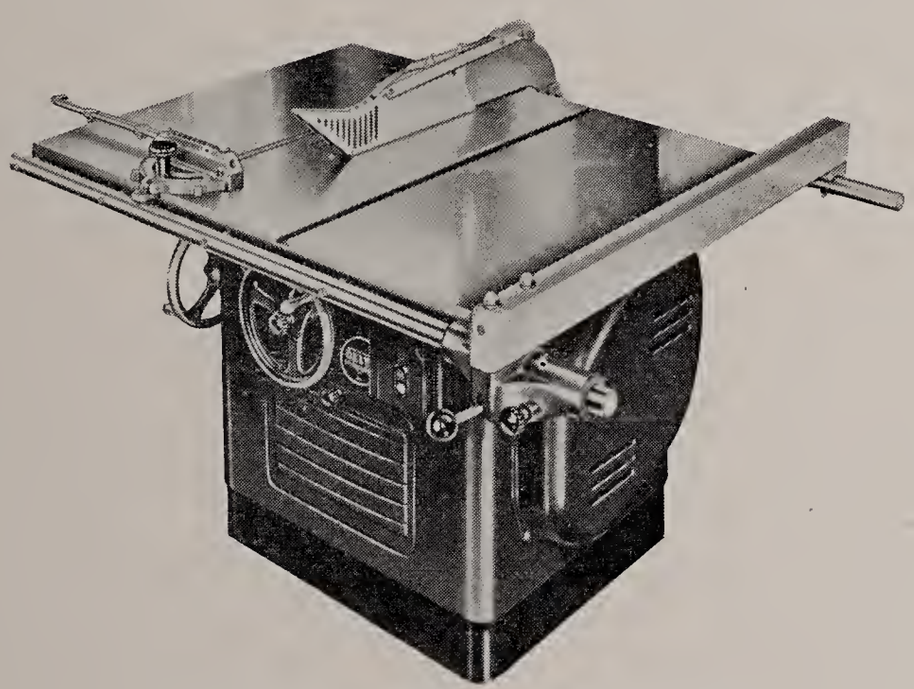

FIG. XI/4.—Motor-driven circular saw.

Band saws

These should be equipped with a tilting table and scale and should be suitable for speeds up to 5,000 ft. per minute, see Fig. XI/5. Band saws with reasonably large throat (approximately 20 in. or larger) are preferred.

Power requirements: Approximately 1 h.p.

Saw sharpening equipment

Band saws and circular saws used for the machining of rigid P.V.C. become blunt very soon owing to the corrosive action of acid fumes

emanating from the material. The sharpening of saw blades by hand is not very satisfactory and requires skill and practice. Saw blades are often ruined by unskilled operators attempting to sharpen them. Automatic saw sharpeners, similar to the one illustrated in Fig. XI/6, save time and cost, especially in a large fabricating shop.
Power requirements: Approximately $\frac{1}{2}$ h.p.

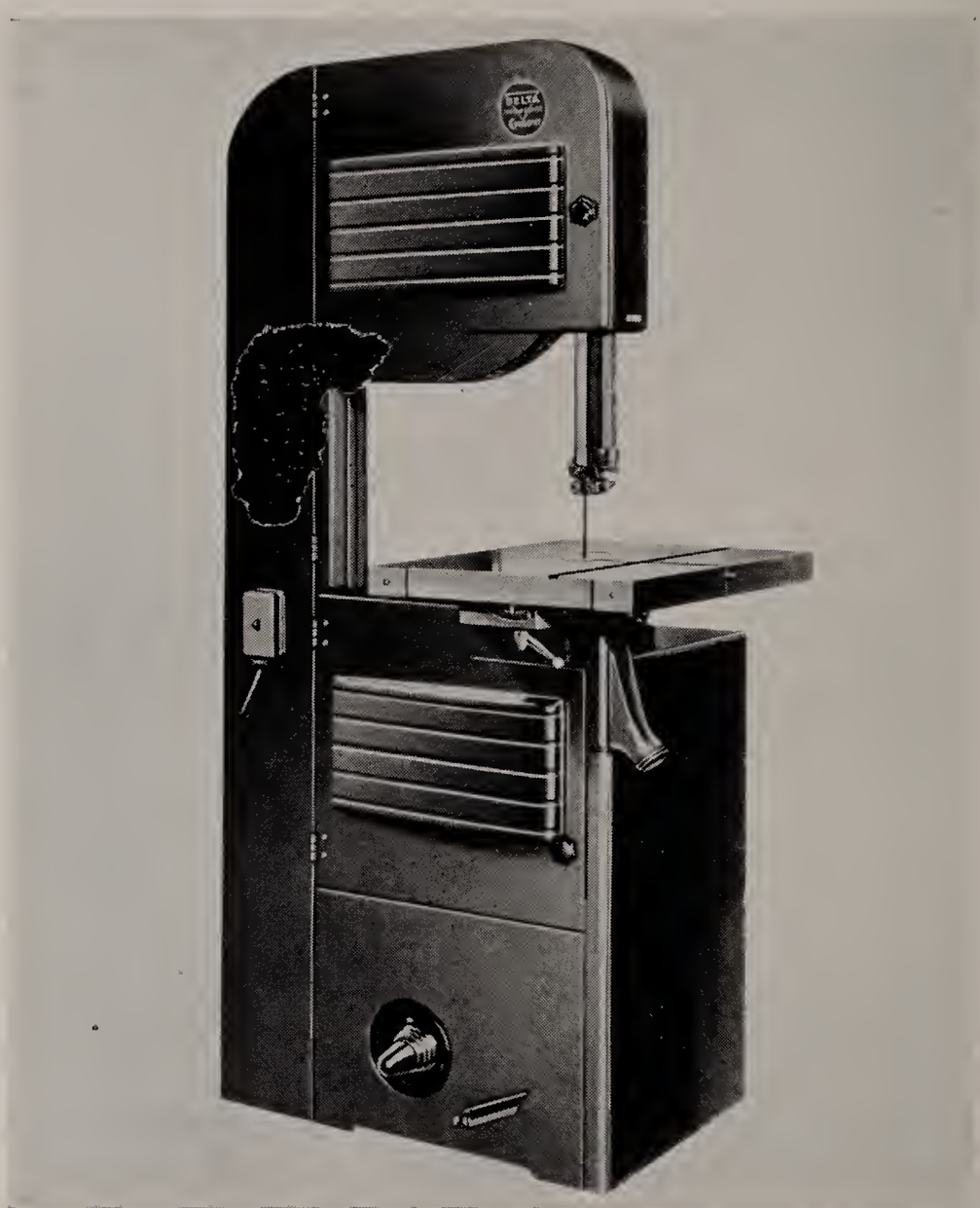

FIG. XI/5.—Motor-driven band saw.

Guillotines (Shears)

Hand operated or foot operated guillotines can be used for the cutting of rigid P.V.C. sheet in thickness up to $\frac{1}{8}$ in.

Lathes

A good wood-turning lathe will afford sufficient scope for most turning operations in a P.V.C. fabrication shop. It allows for the trueing up of pipes, machining of flanges from sheet or rod, i.e. for parts which are machined to reasonably large tolerances. The minimum

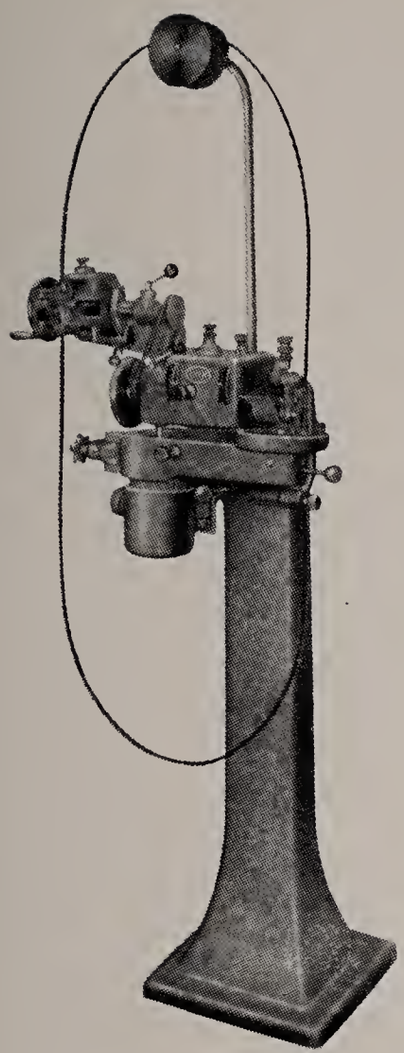

FIG. XI/6.—Saw sharpening machine.

centre distance should be 4 ft. and swing should be at least 2 ft. in diameter. For more accurate turning, such as parts for valves, bolts, screws, etc., a metal working lathe is required. It should be borne in mind that machining (turning) of P.V.C. is carried out at far greater speed than is customary with metals and it may, therefore, be necessary to exchange the motor of the lathe for one of greater speed. A lathe which has been used for a great many years for the machining of metals may have bearings or beds which are worn to a certain extent and the lathe should, therefore, be overhauled to allow for turning at much higher speeds. The gap in the lathe bed should be removable to allow for larger parts to be turned (up to 3 ft. in diameter).
Power requirements: Approximately 2 h.p.

Milling machines

These are sometimes used for the machining of sheets and blocks and for the bevelling of edges.

Shaping machines

There is very little use for a shaper in a P.V.C. fabrication shop.

Spindle drill presses

These should have a stroke of at least 4 in. and speeds from 600 to 4,600 r.p.m. similar to the model shown in Fig. XI/7 and can be employed in addition to the bench model spindle drill press, see Fig. XI/8. The speed of bench models varies from 600 to 4,600 r.p.m. but even higher speeds are recommended for friction welding.

Routers

For repetition work involving complicated contours, routers are often used.

FIG. XI/7.—Pillar drill.

They run at very high speeds (up to 24,000 r.p.m.) and converters are required as they do not operate on ordinary mains currents. Fig. XI/9 shows a motor-driven router of medium size.

Power Requirements: Approximately 5 h.p.

FIG. XI/8.—Bench type spindle drill press.

Hand-operated routers, with speeds up to 45,000 r.p.m., see Fig. XI/10, are very useful in a workshop dealing with thermoplastic materials. They are extremely useful for bevelling the edges of P.V.C. sheets before welding. The use of special guides attached to these hand-routers gives a first class finish to a bevelled edge and saves a considerable amount of time during the subsequent welding operation. In the case of automatic welding, such bevelling with a guided hand-router is a necessity.

Power requirements: $\frac{1}{8}$ h.p.

Abrasive belt finishers

Belt finishers with belts at least 6 in. wide are useful for bevelling

the edges of P.V.C. sheets to be welded; they are also used with advantage to true up sawn edges. They should be equipped with a dust collector and have, if possible, a tilting table.

Power requirements: Approximately 1 h.p.

Very much larger belt finishers commonly used by joiners and carpenters are occasionally installed in fabricating shops for P.V.C. but they are rather exceptional.

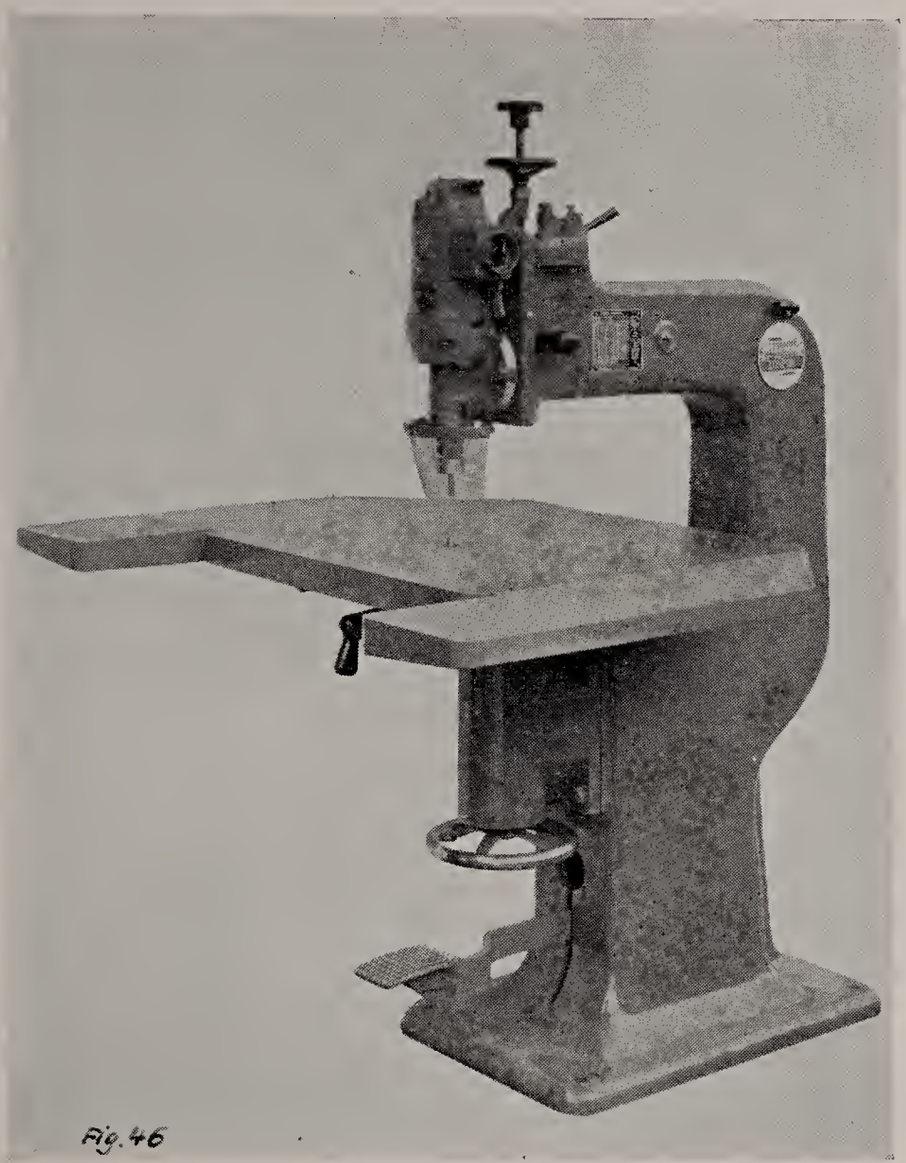

FIG. XI/9.—Motor-driven router.

Services

Adequate supplies of water, town gas and electric power should be available. The machines installed in a medium sized P.V.C. workshop will require less than 30 Kw.

Compressed air is required for welding; this can be obtained from a large compressor with compressed air lines extending all over the workshop or from a number of small compressors. The first alternative is not always satisfactory as the supply lines from the compressor very often carry water and oil which, in turn, will get into the welding torches

and either ruin the electric heater elements or deposit an oily film or water on the materials to be welded, with defective welds as a result.

FIG. XI/10.—Hand-operated router for chamfering polyvinyl chloride sheets.

The insertion of filters can prevent this to a certain extent but inspection of the filters at reasonably short intervals is necessary to draw off water and oil and to exchange clogged filter elements. The provision of an adequately large air receiver (capacity 200 cubic feet) eliminates most of these troubles and it also permits the installation of the compressor outside the workshop, thus reducing the noise in the workshop.

The purchase of a compressor of at least 200 cu. ft. capacity per hour is recommended; it should be capable of supplying compressed air of at least 100 p.s.i. pressure.

Power requirements: Approximately 3 h.p.

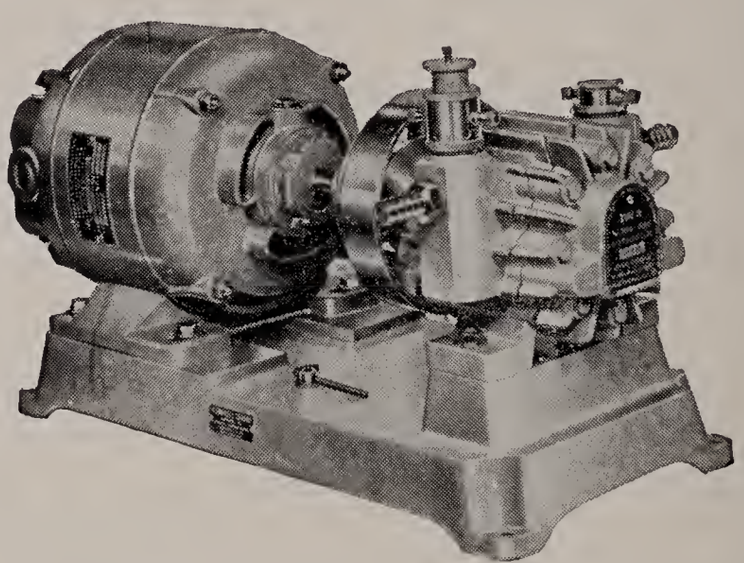

FIG. XI/11.—Small portable compressor.

Small portable compressors, see Fig. XI/11 are a better solution and on a long run cheaper in use than larger ones.

Power requirements: Approximately $\frac{1}{2}$ h.p.

Space requirements and layout of a workshop for the fabrication of P.V.C.

The space requirements of a workshop dealing with P.V.C. fabrications depend entirely on the volume of operations. 500 to 1,000 square

feet are the absolute minimum at which small scale fabrications can be carried out at an economical level. 2,500 to 5,000 square feet would be required for a workshop of medium size. The height of the premises should be sufficient to allow for the erection of pipe work and duct work in the vertical position especially for welding; the workshop should, therefore, be at least 12 to 15 feet high; lifting devices for the handling of steel tanks should be available. Floors should be reasonably level and there should be sufficient space left to assemble pipe sections and ducts for checking before despatch to customers.

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CHAPTER XII

GENERAL INFORMATION FOR THE WORKING AND FORMING OF POLYVINYL CHLORIDE

Machining of rigid polyvinyl chloride

The procedure in machining rigid P.V.C. varies somewhat dependent upon the particular material to be machined and reference is therefore made to the technical literature issued by the manufacturers of P.V.C. sheet, blocks and rods.

The recommendations given below will be found applicable to the majority of materials on the market.

The cutting and machining of rigid P.V.C. differs considerably from that of light alloys and timber, although here statements are frequently met that the procedure is very similar; rigid P.V.C. is, for instance, a bad conductor of heat, and cooling by means of compressed air or by means of liquids (soapy water or plain water) has to be provided which is not necessary for the machining of most metals or timber.

Tools are soon blunted due to thermal degradation of the P.V.C., as hydrochloric acid is set free which will attack them. For this reason relatively small cuts are advisable; larger cuts create much more heat and consequent degradation of the material. Another prerequisite for successful machining and cutting of rigid P.V.C. is high speed. Most machine tools work at low speeds and have to be modified for this type of work.

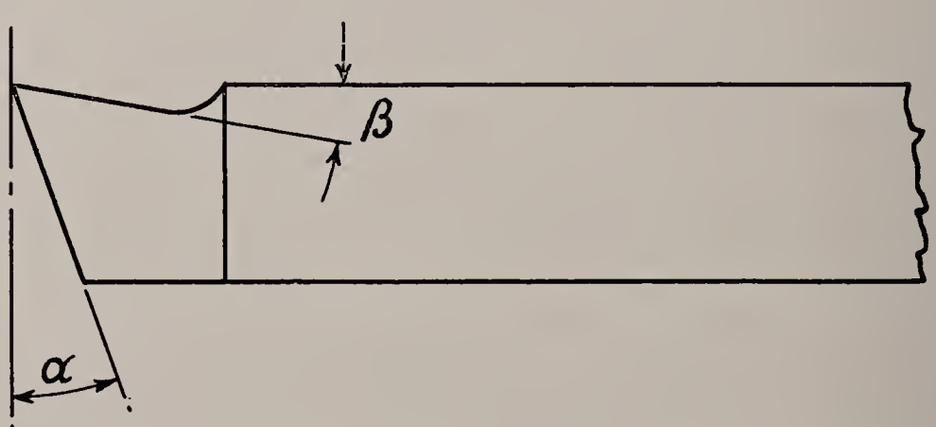

FIG. XII/1.—Turning tool for rigid polyvinyl chloride.

Turning

Hardened steel or carbide tools should be used. As previously said the tools quickly become blunt, but their life can be prolonged considerably by cooling. Speeds up to 1,000 ft./min. are average and the

depth of cut should be as small as is practicable: larger cuts will not only create more heat but will also cause notches and embrittlement of the material.

Fig. XII/1 shows the form of a simple straight turning tool indicating a top rake angle of 10° and a front rake (clearance angle) of 20°. The depth of the cuts may be varied within wide limits (0·060 in. to 0·400 in.). Chipping and chattering is mainly caused by a low top rake—overheating and burning by a low front rake. The feed should be adjusted to allow for smooth working—excessive feed results in chipping and rough surfaces, insufficient speed in overheating and burning.

For rough cutting, feeds up to 0·020 in./rev. are permissible, for subsequent turning feeds between 0·004 in. to 0·008 in./rev. are recommended. The cutting depth should be chosen according to the type of work and cross-section of the workpiece, i.e. for roughing it may be as high as 0·400 in. whilst for final turning 0·020 in. to 0·040 in. are preferred. Working with smaller cutting depths causes the swarf to curl around the tool bit and frequent stoppages are needed for its removal.

Milling

Milling cutters with a positive front rake of approximately 10° and a 20° top rake, working at a speed of 300–1,500 ft. per minute, and feeds of 0·004 in. to 0·040 in. give best results. The swarf should be removed at frequent intervals and cooling by means of compressed air may be required.

Drilling

Drilling is one of the most frequent operations in the course of fabrication of rigid P.V.C. Drills used should have an included point angle of 130° to 140° (see Fig. XII/2) and have a steep helix angle. Special type drills made for drilling acrylics are recommended for this type of work, alternatively drills made for aluminium can be used.

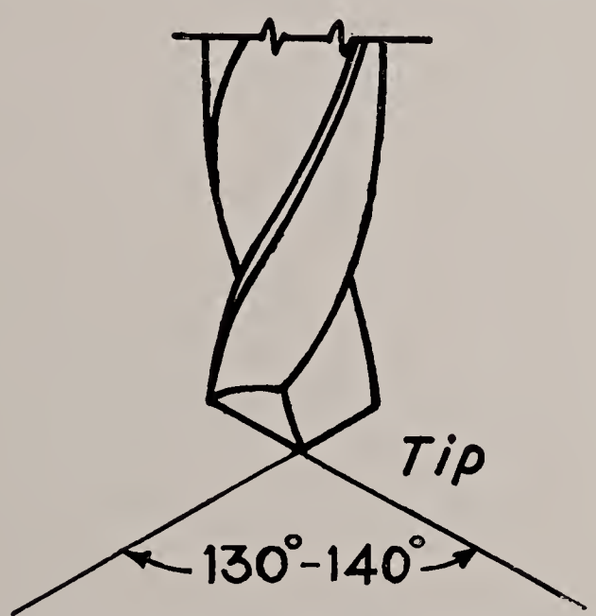

Fig. XII/2.—Recommended shape of drills to be used for rigid polyvinyl chloride.
Note included point angle of 130°–140°.

Speeds may vary between 50 and 150 ft./min. with feeds from 0·004 in. to 0·020 in. per rev. Drilling in two stages is often advisable—i.e. a smaller hole should be drilled at first to be followed by drilling to the required size. It should be borne in mind that the material heats up during drilling and that it will subsequently contract on cooling.

It is therefore advisable to use drills approximately 0·002 in. to 0·003 in. larger than the actual size of the hole to be drilled. Drills should be frequently lifted during the operation to prevent overheating and binding.

Holes larger than 1 in. in diameter should be cut with trepanning tools with adjustable blades. Tools with ejectors are preferred—but the ejector should be mounted separately so that it does not turn with the drill.

Threads can be cut on a lathe or by means of standard taps and dies using soluble oil or a silicon emulsion as a lubricant. Blunt tools will damage threads.

Sawing

Circular Saws. Most rigid P.V.C. sheets can be cut on a circular saw. The blade of the saw should be selected according to the thickness of the material to be cut, and as a rule blades with a finer pitch should be used for thinner materials, to prevent crumbling and tearing at the edges.

The teeth of the saw should exert a slicing action and the saw should therefore have a negative rake (Fig. XII/3) and little or no set. The

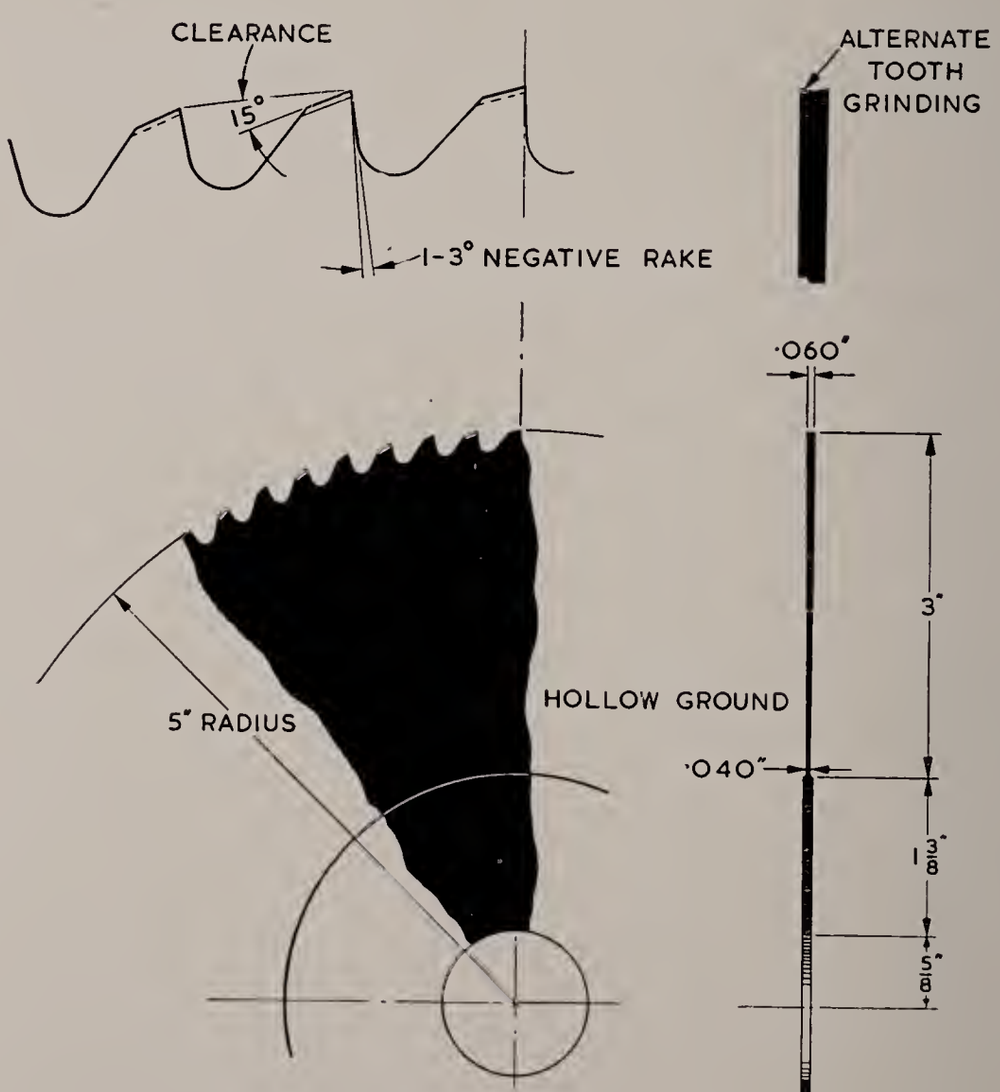

FIG. XII/3.—Recommended type of saw suitable for rigid P.V.C.

saw blade should be of substantial thickness to prevent whipping and should be hollow-ground to reduce overheating, especially when cutting heavier sheets. The blades should be of suitable size—but not too large in diameter (approximately 12 in.–14 in.); they should not extend too much over the sheet when cutting to reduce friction and to yield a smooth and even cut. The pitch of the blades should be approximately $\frac{1}{8}$ in. A speed of 5,500 to 7,500 ft./min. corresponding to 1,500–2,000 r.p.m. and a 14 in. saw is recommended with feeds of 2–5 ft. per minute, depending on the thickness of the sheet.

Circular saws are suitable for the cutting of rigid P.V.C. up to $\frac{3}{4}$ in. thickness—band saws should be used for cutting heavier sheets, blocks and rods.

Band Saws: Band saws used for rigid P.V.C. should have a slight set and a slightly finer pitch than circular saws (12–18 teeth per inch). Cutting speeds of 500–3,000 ft./min. are recommended with feeds varying from 2–20 ft./min. depending on the thickness of the material. Guiding rollers and tension rollers should be provided on the machine to reduce friction to a minimum.

Planing

Planing with hand tools is a rare operation in a P.V.C. fabrication shop and even rarer is the use of motor driven planers.

Routing

Routers are often used instead of milling machines for cutting, shaping and recessing of rigid P.V.C. Routing bits with one or two cutting edges are employed. The speed of a router is considerable and may be as high as 6,000 ft./min. Cutters up to $\frac{1}{2}$ in. in diameter, for instance, are driven at approximately 24,000 r.p.m., heavier cutters at approximately 15,000–18,000 r.p.m. Removal of swarf and cooling by means of compressed air is required at frequent intervals.

Punching and cutting

P.V.C. sheets up to $\frac{1}{8}$ in. can be cut with shears or a guillotine. Care should be taken that the material does not splinter. Several pieces can be cut on a guillotine at the same time, provided the combined thickness does not exceed $\frac{1}{8}$ in.

For the punching of rigid P.V.C. sheets certain precautions have to be taken to overcome the inherent brittleness of the material which should be pre-heated so that it is definitely in excess of 80° F. (30° C.). This can be achieved by pre-heating in an oven or by laying the sheet on a steam-heated platen.

Grinding and polishing

Bandfacers or carborundum and emery grindstones can be employed.

Bandfacers are used for relatively long and large surfaces and for bevelling—grindstones for smaller articles.

Felt polishing mops are used for polishing with ordinary polishing compounds, such as waxes, Tripoli, iron oxide and the like. A finer polish can be obtained by means of special waxes or metal polishing liquids.

Both types of machines are driven by motors with 1,500 or 3,000 r.p.m.

Heat-forming of rigid polyvinyl chloride

Polyvinyl chloride as a thermoplastic material can be softened and formed at temperatures above its softening point (or range). The various types of rigid P.V.C. vary slightly in their softening range which in general commences around 175° F. At higher temperatures the material becomes soft and pliable—at the same time its tensile strength diminishes gradually and becomes zero around 320° F. Elongation increases at first—from 10 to 15 per cent. around 70° F. to 300–400 per cent. at about 212° F. and diminishes gradually thereafter; at 300° F. elongations of 50–60 per cent. are usually observed.

Heat forming of rigid P.V.C. sheets should, therefore, be performed within a temperature range where both tensile strength and elongation are reasonable.

The most favourable conditions are met between 260°–285° F.—working at lower temperatures allows for a higher degree of deformation, but the articles produced are not dimensionally stable and shrink afterwards. Forming at higher temperatures yields articles which are dimensionally stable but because of the reduced mechanical properties of the material at these higher temperatures much shallower articles will be produced from materials of comparative thickness—i.e. the degree of deformation permissible will be reduced.

The speed of operation has also some bearing on the properties and performance of the hot-formed article.

Rigid P.V.C. has a 'memory' i.e. it has a tendency to regain its original shape while it is still soft and plastic. It is therefore necessary to chill hot-formed articles by means of compressed air or water while they are still in the mould and under pressure.

Various processes can be applied for the heat-forming of rigid P.V.C. In the case of rigid P.V.C. pipes, for instance, bending, flaring, belling and shrinking can be performed. Rigid P.V.C. sheets and foil can be bent, blown, deep-drawn and vacuum formed.

Bending

Bending of rigid P.V.C. sheets is a simple process which requires little in the way of tools and equipment.

Short pieces can be bent over the edge of a work bench. The sheet to

be bent is placed on the top of the bench in such a way that the line along which bending is required runs over the corner of the bench top. A heavy wooden block with a straight edge is then laid on top of the sheet to hold it down, and also to restrict heat transfer by radiation when a preheating torch, bunsen burner or the like is played over the 'bending line' previously marked with chalk or pencil. The protuding end of the sheet will gradually soften and bend towards the vertical

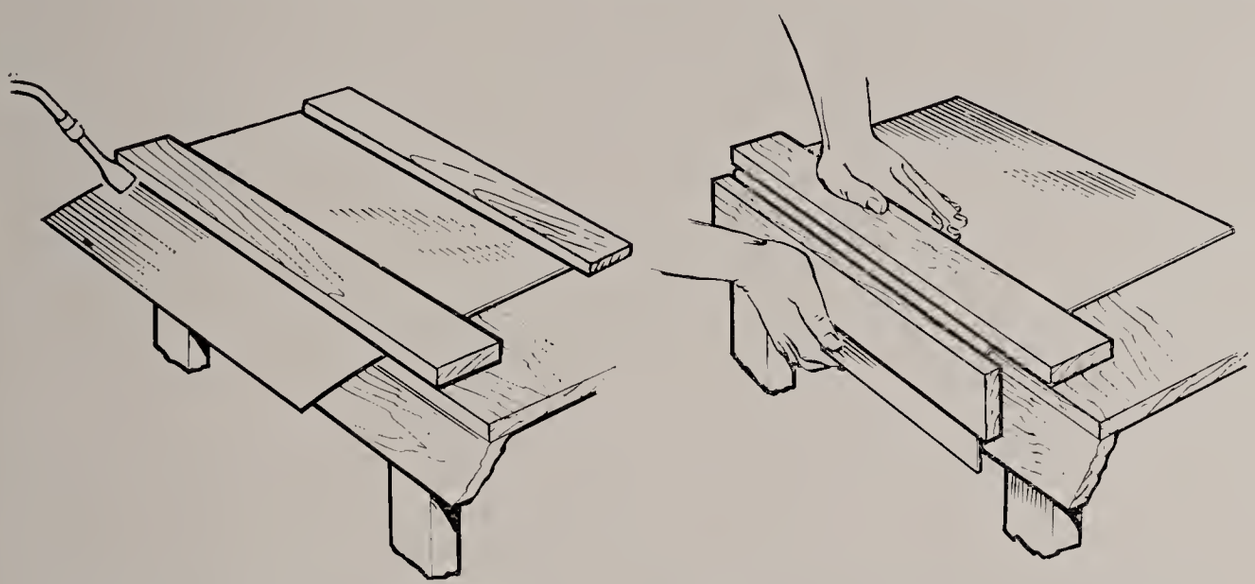

FIG. XII/4.—Bending of rigid P.V.C. sheet using a blow torch and wooden blocks.

plane of the bench-top—when this stage is reached a plain wooden batten is pressed against the vertical leg of the bench top with the result that a neat corner is formed in the sheet. See Fig. XII/4. For repetition work and for the bending of larger sheet proper bending machines should be employed (see page 111).

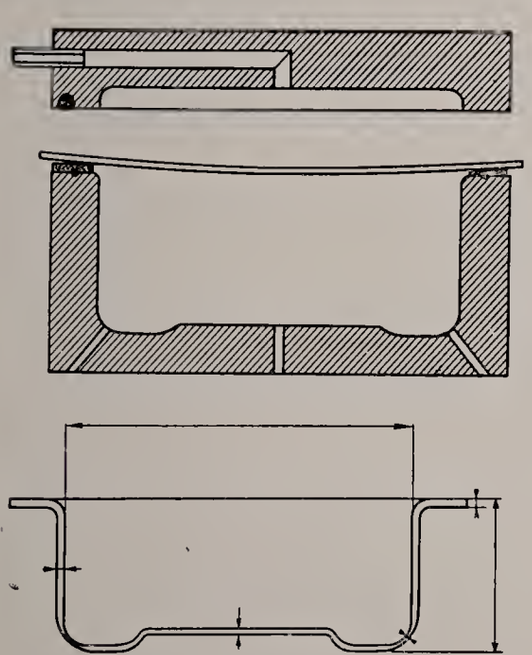

FIG. XII/5.—Schematic diagram of an arrangement for blowing rigid polyvinyl chloride articles.

Bending over a wooden block with radiused corners gives better results. The radius on these corners should be selected in accordance with the thickness of the material to be bent and should be at least twice this thickness. The preheated area for bending should be at least six times as wide as the thickness of the sheet.

Details relating to the bending of rigid P.V.C. pipes will be found in Chapter XIV.

Blowing

Another simple process of heat-forming rigid P.V.C. is blowing, for instance, for the manufacture of bottles.

Extruded P.V.C. tubing is transferred to split metal moulds whilst it is still hot and plastic. The moulds are then closed and pressure (compressed air) is applied to expand the P.V.C. tubing which thus conforms to the internal shape of the moulds. Blowing is also applicable to rigid P.V.C. sheet or foil which has to be preheated and softened before it is introduced to the mould. Fig. XII/5.

Deep drawing

Air-operated or hydraulically-operated presses, Fig. XI/3, with reasonably low pressure ratings are suitable for deep drawing. It is advisable to select equipment which works at high speed. Other types of presses, such as hand-operated and foot-operated presses, friction presses and the like are equally suitable but not as economical in use.

P.V.C. has very good hot forming characteristics, but obviously there are limits beyond which the material will not stretch. The height of a deep drawn round article, for instance, should not be greater than approximately 80 per cent. of its diameter. Sharp corners should be avoided in the form as they represent notches and will cause tearing. Fig. XII/6.

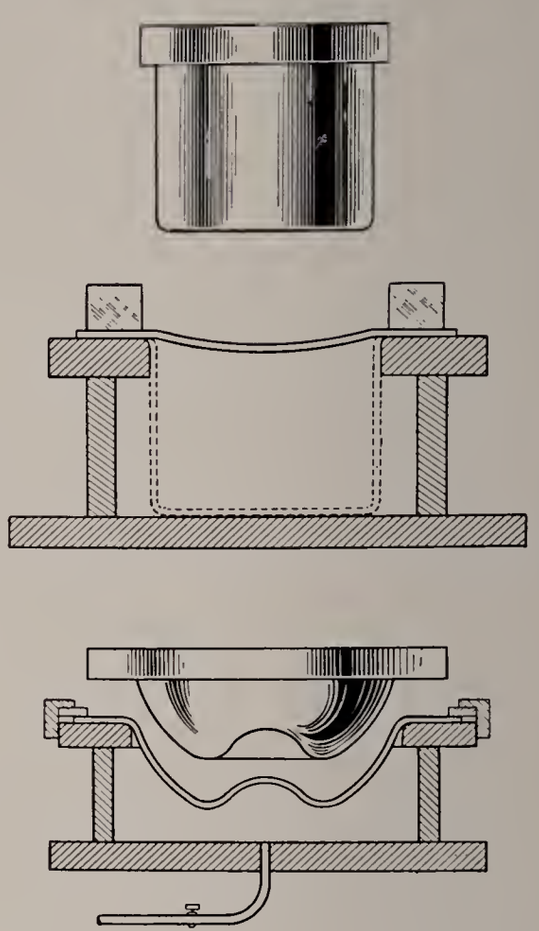

FIG. XII/6.—Schematic diagrams showing arrangements for the deep-drawing of articles from rigid P.V.C. foil and sheet.

Pressing

This method of heat forming rigid P.V.C. sheets is rather conventional and has much in common with the well known compression moulding process for thermosetting resins. Male and female moulds are employed with the preheated and softened sheet inserted between them. Reasonably deep draws can be achieved but care should be taken to hold the sheet firmly at the edges to prevent slipping. A slight taper has to be provided and undercuts must be avoided to make the withdrawal of the male part of the mould possible. A press similar to that shown in Fig. XI/3 is suitable for forming sheets by

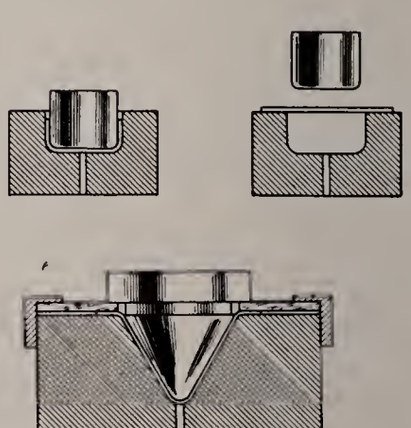

FIG. XII/7.—Schematic diagrams showing arrangements for pressing articles from rigid P.V.C. sheet.

this method. Schematic diagrams showing the arrangements and details of the moulds for pressing cylindrical and conical parts are given in Fig. XII/7.

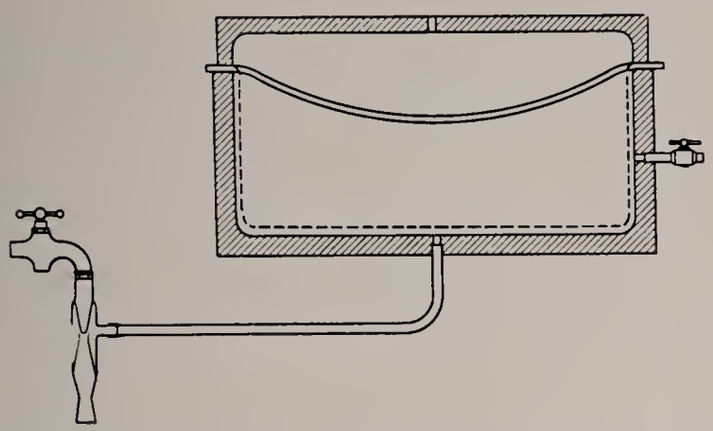

FIG. XII/8.—Schematic diagram of an arrangement suitable for vacuum forming articles from rigid polyvinyl chloride foil.

Vacuum forming

Forming on vacuum forming machines is, in general, only undertaken on relatively thin materials. Fig. XII/8 shows the general arrangement for vacuum forming. The material rigidly clamped down on the surrounding edges is preheated by infrared heaters and then caused to collapse into the mould underneath by the application of a vacuum. Very fine details and reasonably high production figures can be obtained by this method.

Forms and moulds

It is rather difficult to give standard rules relating to the construction of moulds for the hot-forming of P.V.C. In the case of pressing, for instance, male and female moulds are required. Moulds should be of regular shape to allow turning of at least part of the mould on a lathe. The thickness of the material to be used is also of importance—as the clearance between male and female parts of a mould is strictly limited. Strengthening of the moulds by metal surrounds, supports, etc., is not required in cases where a small number of components has to be produced. For mass production, however, much more complicated moulds, with spring-loaded retainer rings (to hold the P.V.C. sheet in position whilst it is being stretched) and air operated ejectors are needed.

Most of the forms and moulds used are cheap. They can be built from wood, Plaster of Paris or special phenolic forming compounds, such as 'Stonex' and the like. 'Stonex' is also available in a modified form containing metal powders—moulds made from this compound are heat conducting and will therefore not overheat.

Wood is, of course, cheaper than all the other materials mentioned. Any well-seasoned hardwood, free from knots and resin, will be found suitable. Repeated use of a wooden mould at short intervals will increase the temperature of the mould and bring out the structure of the wood even in a highly polished form. Oiling or varnishing will help a great deal to retard this—but not prevent it entirely. For long runs metal forms are more suitable but they have to be preheated to a

temperature of approximately 140° F. to prevent chilling of the P.V.C. sheet.

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CHAPTER XIII

LINING OF TANKS AND VATS WITH UNPLASTICIZED AND PLASTICIZED POLYVINYL CHLORIDE

Lining of Tanks and Vats with Unplasticized Polyvinyl Chloride

One of the most important industrial applications of polyvinyl chloride is lining of tanks, containers and vats; rigid unplasticized, and plasticized P.V.C. are used for this purpose.

Most of the information contained in this chapter refers to German and American materials and methods of lining, as far more work on P.V.C. lining has been undertaken in Germany and the United States of America than in other parts of the world.

Preference is given to unplasticized P.V.C. for lining in Germany and in European countries, whilst the Americans use plasticized P.V.C. for similar applications.

Failures with plasticized P.V.C. linings in Germany, in the earlier stages of development, led to the belief that plasticized P.V.C. was unsuitable for tank linings, and numerous references in German technical journals emphasize this, but according to more recent reports plasticized P.V.C. is nowadays recommended for tank linings in Germany, particularly so in the Eastern Zone.

The greater part of the instructions for lining with P.V.C. foil in this book has been taken from a paper by Sirot (*2*), whilst the information on methods for the lining with plasticized P.V.C. are mainly based on American information.

Strict attention to the lining methods given in this chapter will result in linings which will give satisfaction in use; the employment of somewhat different materials and cements may make certain modifications necessary.

Lining of Tanks with Unplasticized P.V.C. Foil (2)

Lining of steel tanks

The lining of steel tanks with unplasticized P.V.C. foil (varying in thickness from 0·030 to 0·050 in.) requires a considerable amount of skill and the recommendations given below should be followed as strictly as possible.

Nearly all metals can be lined with unplasticized P.V.C. foil, the

exceptions being lead and some of the light alloys, but in the majority of cases steel tanks only will be lined using this technique.

The shape of the tank is immaterial but all parts to be lined should be freely accessible. Best results can be obtained with tanks having a wall thickness varying from $\frac{3}{16}$ in. to $\frac{3}{8}$ in., as sufficient heat can be stored during the heating up operation to ensure proper degassing of the cement before the film is attached. In the case of thinner walled tanks additional heat may have to be provided during the lining operation and this considerably complicates the process. On the other hand, with tanks fabricated from plates thicker than $\frac{3}{8}$ in. overheating may occur during the warming up operation and this may destroy the cement; the preheating should, therefore, be gradual and larger areas should be heated simultaneously.

Riveted tanks are, in general, unsuitable for lining with unplasticized P.V.C. foil as the stretching of the foil over the rivet heads may cause stresses which eventually lead to cracks or fissures if considerable temperature changes of the liquid contained in the tank take place.

Riveted tanks which are not subject to pressure can, however, be lined by this method, provided the riveted seam is covered with a strip of metal which would also, at the same time, cover the metal overlaps.

Another method to make riveted tanks suitable for lining is covering the rivets with a layer of concrete approximately $\frac{1}{4}$ in. to $\frac{3}{8}$ in. thick before lining.

Tanks to be lined should be of sufficient strength to prevent distortion; tanks made from thin gauge sheet should be strengthened with stiffeners. The slight deformations which may occur during filling or emptying of the tank have no detrimental effect on the plastic lining, but continuous vibrations should be avoided as they cause detachment of the foil from the walls of the tank. In cases where continuous vibrations occur an elastic buffer layer should be provided between the foundations and the tank.

Preparation of the tank for subsequent lining

Careful preparation of the steel tank prior to lining is most important. Grooves which frequently occur where flanges and sockets are attached should be filled in by welding. Welds should be thoroughly cleaned from dirt and slag and whenever possible roughened up to improve adherence of the foil. In the case of steel tanks this can easily be achieved by sand blasting, shot blasting and grit blasting. Sand blasting is not favoured nowadays as the workmen may in time suffer from silicosis. Figs. XIII/1a, b, c, d and e illustrate the correct technique for welding steel tanks, they also show typical errors to be avoided.

Other metals, for instance, copper and aluminium, may also be cleaned and roughened up by blasting, but much more care has to be taken than in the case of steel. It is rather difficult to specify the degree

of roughness required. The appearance of the roughened surface should be similar to that of emery paper No. 3 or 4. Light metals are easily damaged by blasting and the roughening up of their surfaces is preferably achieved by chemical treatment after removal of oil films and fat with suitable solvents, such as carbon tetrachloride or trichlorethylene. A solution containing 30 per cent. sodium hydroxide, 10 per cent zinc oxide and 60 per cent. water is then applied to the clean surface

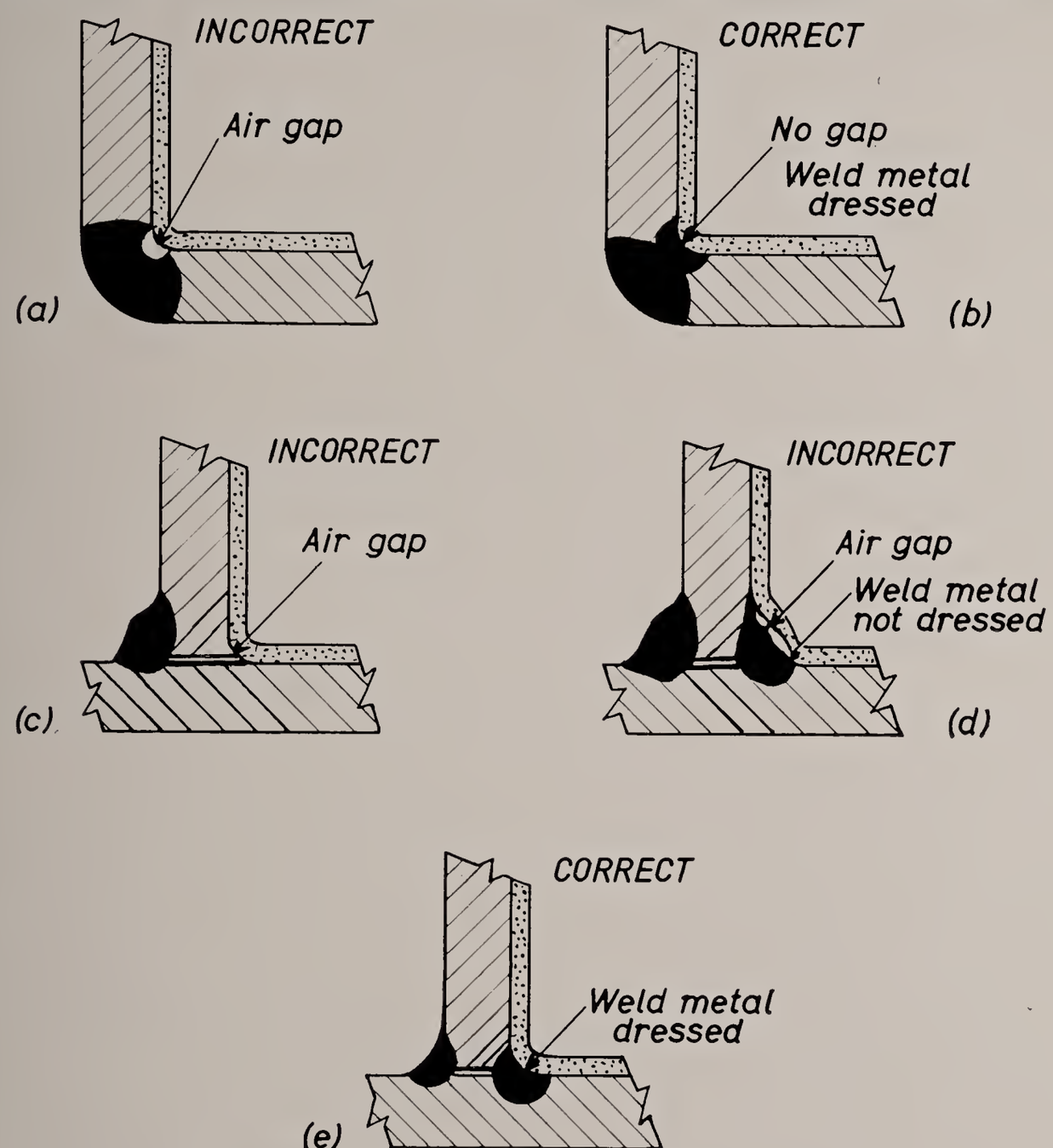


FIG. XIII/1.—Preparation of steel welds prior to lining.
correct: 1b and 1c.
incorrect: 1a, 1c, 1d.

with a thick rag, care being taken that the whole surface is uniformly covered with the solution. Once the surface is covered with a uniform layer of zinc the solution is washed off and the surface properly dried. The solution treatment should not be extended over too long a period otherwise a somewhat spongy coating will result. Anodized aluminium

tanks are well suited for lining with unplasticized P.V.C. foil. Tanks made of light alloys containing larger percentages of magnesium should be treated with a solution containing 1 per cent. of aluminium chloride.

The metallic surfaces cleaned and treated by one of the methods specified above should be carefully brushed with a soft hair brush and all dust should be removed with a vacuum cleaner. Insufficient cleaning results in bad bonding. Mechanically roughened surfaces re-oxidize very quickly and the first coat of the cement should therefore be applied immediately after blasting and cleaning.

Cements used

For the lining of steel and metal tanks P.C.10 and P.C.A.20 cements are recommended, alternatively, any of the equivalent cements produced in other countries, such as Tensol 50, Chemidus 2.A.1., and the like, may be employed. For the lining of vats made of wood and concrete the use of cement P.C.13.A.M. or P.C.D.13 and the like is suggested.

Application of the cement

The cement (P.C.10 or the like) should be of sufficiently low viscosity so that it can penetrate into all pores and voids of the metallic surface. The solvent vapours emanating from the cement are intoxicating and proper ventilation should be provided to minimize effects detrimental to the health of the workmen. This can be achieved by an exhaust system with flexible tubing; the solvent vapours are heavier than air and the intake tube should be located at the lowest part of the tank. For work in pressure tanks gas masks should be worn but removal of the solvent vapours is still required.

The cement should be applied uniformly by brushing on several coats at one to two hourly intervals. The last coat should be left to dry for approximately 15 hours. The indication that sufficient cement has been applied is the appearance of a smooth and shiny film covering the entire metallic surface.

Figures for the consumption of cement vary from application to application, but using P.C.10 for instance, approximately 4 to 5 oz. of cement are required per square foot.

Once the final coating has been applied and left for 15 hours bonding of the foil should follow almost immediately as the cement has a tendency to decompose when left unattended for several days. If, for any reasons, such long delays cannot be avoided a further coating of cement, preferably mixed with methylene chloride in the proportion of 1 : 1, should be applied.

Thorough degassing of the cement film is required before applying the P.V.C. foil. This is effected by heating the tank from the outside to a temperature of approximately 266° F. to 284° F. (130° C. to 140° C.).

One can watch the progress in degassing quite easily; small gas bubbles appear in the cement film which becomes opaque and silver-grey in colour. Once the formation of new gas bubbles has ceased degassing can be considered as complete and at this stage the cement has acquired its proper plasticity. If the above changes do not take place, as described, or if a dark-grey colour appears instead of a silvery-grey, this can be taken as a sign that the solution has been applied too sparingly and a further coat of cement will be needed. Overheating of the cement is recognized by discolouration and should be avoided at all costs as the cement will lose its bonding properties.

The temperature limits given, i.e. 266° F. to 284° F. are reasonably critical. Such temperatures are necessary to remove the solvent completely and to plasticize the P.V.C. cement, furthermore to make the unplasticized P.V.C. foil soft and pliable when applied.

Preparation of the foil

All dust and dirt has to be removed from the foil and oily or fatty surface films should be removed with methylene chloride if necessary. The foil should then be cut to size and brushed thoroughly with a suitable cement, for instance P.C.A.20. One single coat applied evenly will be sufficient. The consumption of P.C.A.20 cement averages 1 oz. per square foot.

Details of the bonding processes

It is assumed that the tank or container has been heated up in parts to the correct temperature and that the cement has been degassed properly. In the case of small containers the entire area to be lined should be preheated, but in the case of larger tanks preheating has to be carried out progressively as one can only line a somewhat limited area within a specified time. The size of the area which should be preheated in one operation depends on the preheating equipment available and the speed and skill of the operators as well as upon the heat capacity of the vessel (determined by the thickness of the metal). Taking an average metal thickness of $\frac{1}{4}$ in. to $\frac{3}{8}$ in. and average working conditions, one could say that an area of 10 to 15 square feet could be preheated and handled at the same time.

The bonding operating is comparatively simple. The conduction from the preheated metallic surfaces causes the foil to become soft and pliable so that it can be pressed on to the metal with a soft rag or a roller starting from one end and pressing slowly to foil applied to the surface until its entire length is attached. Stretching of the film should be avoided at all costs.

The procedure for the lining of smaller containers varies slightly from that employed for large tanks.

Lining small containers

In the case of smaller tanks and containers the base should be lined first, but it is recommended to extend the foil approximately 1 in. up the sides using a wooden spatula for pressing the foil into the corners and edges. The loose parts of the foil extending upwards should be kept away from the sides so that they do not stick prematurely and they should only be fixed to the sides when all four corners have been lined properly. In the case of cylindrical containers care should be taken to cut the foil for lining the base at least 1 in. larger in diameter than required, in order to prevent overlapping. Once the bottom surface has been lined properly the sides can be covered without difficulty. (The design of the tank or container should, of course, be suitable for lining, see Fig. XIII/2a; dished bottoms such as shown in Fig. XIII/2 b are unsuitable for this purpose.)

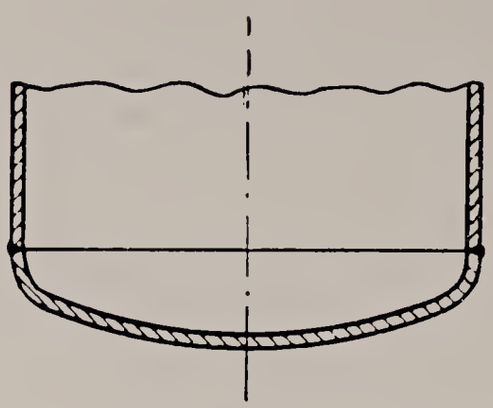


FIG. XIII/2a.—Dished bottom of steel tank—suitable for lining with P.V.C.

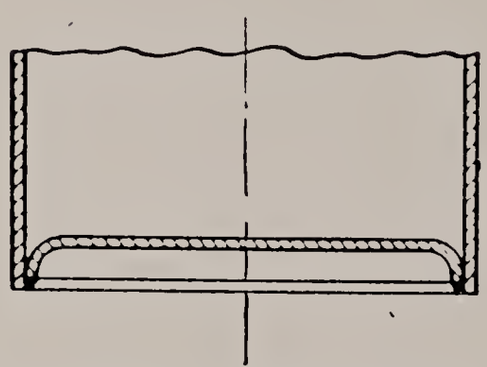


FIG. XIII/2b.—Dished bottom of steel tank—unsuitable for lining with P.V.C. due to method of construction adopted.

Lining large tanks

The lining of containers up to 6 ft. in height can be performed as previously described. Care should be taken to keep the bottom part of the tank clean. Damage to the bottom lining, due to nailed boots, can be avoided by providing the operators with plimsolls.

The lining of tanks exceeding 6 ft. in height requires step ladders or scaffolding, and in such cases it is the practice to line the sides of the tank first, proceeding in sections from the top to the bottom and leaving the lower ends of the foil unattached. The scaffolding is then removed and the base lined with P.V.C. foil extending slightly up on the sides; the unattached parts of the side linings are then cemented over these.

Horizontal tanks can be put on rollers and rotated to facilitate lining.

The greatest difficulty in lining large containers is preheating. Obviously, this preheating operation has to be performed from the outside and proper communication between the workmen inside the tank and those working outside may not always be possible. It has been found that marking off the outside and inside area of the tanks in corresponding sub-divisions, which are numbered, greatly helps in

this case, as the operator outside can communicate to the man inside the tank his intention to preheat area 7 and 8, for instance; obviously, the man attending to the lining operation will then line area 7 and 8.

Lining of flanges and sockets

The tubular section of a flange is lined with a rigid P.V.C. tube of the corresponding outside diameter. The pipe is slightly preheated to make it plastic and then cemented to the inside of the tubular section of the flange with the P.V.C. pipe extending on each side, i.e. into the vessel and over the flange. It is then cut to size, slightly warmed up and flared over the flange and over the outlet in the tank where it is overwelded with a filler rod. In the case of larger flanges this flaring is, however, not always possible and in such cases the P.V.C. pipe is cut to the exact length, the surface of the flange is lined with P.V.C. foil and a weld applied to join the P.V.C. pipe with the flange liner. P.V.C. pipes are only available in certain specified dimensions, designers should therefore specify the dimensions of inlets and outlets of tanks to be lined in such a way that the inside of these fittings corresponds as near as possible to the outside diameter of standard P.V.C. tubing.

Lining in sections

Large tanks have obviously to be lined in sections and the joining of the individual sections can be carried out by various methods, for instance, the sheets can be overlapped with an overlap of approximately 1 in. In such a case it is advisable to clean the previously laid foil along the edge where overlapping will take place with methylene chloride before applying the next section. Approximately 2 or 3 coats of P.C.10 cement are then applied. Cleaning with methylene chloride and the brushing on of the cement should only be carried out when the metal is quite cold otherwise the cement will not stick properly. The free edges can then be overwelded with a P.V.C. filler rod of approximately $\frac{1}{16}$ in. diameter. The sealing by means of a filler rod is a necessity for tank linings subjected to repeated mechanical stresses caused by stirrers and the like. All traces

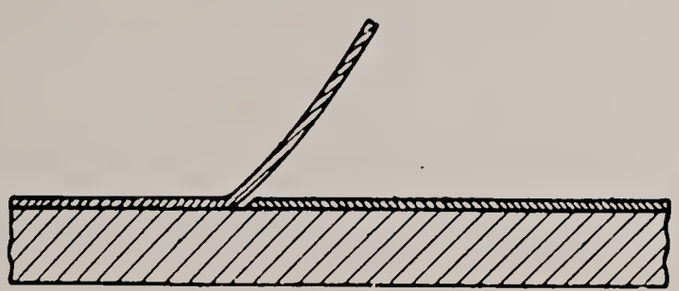


FIG. XIII/3a.—Details of method for lining a tank with rigid P.V.C. foil.

FIG. XIII/3b.—The loose end of the P.V.C. foil is stuck over the adjoining foil and sealed by a lap-weld.

of cement have to be removed before welding, either by washing with methylene chloride or by scraping. The welded seam should be dressed afterwards with suitable tools to leave a smooth surface. Fig. XIII/3a and 3b.

The alternative to this method is lining without overlapping and leaving a gap of approximately $\frac{1}{16}$ in. between individual sections, the edges of the foils are then bevelled and the space between them is filled in by welding with a P.V.C. filler rod of $\frac{1}{8}$ in. thickness. The welds are then dressed with suitable tools and a strip of P.V.C. foil approximately $\frac{3}{8}$ in. wide, is overwelded. Fig. XIII/4a, b, c and d.

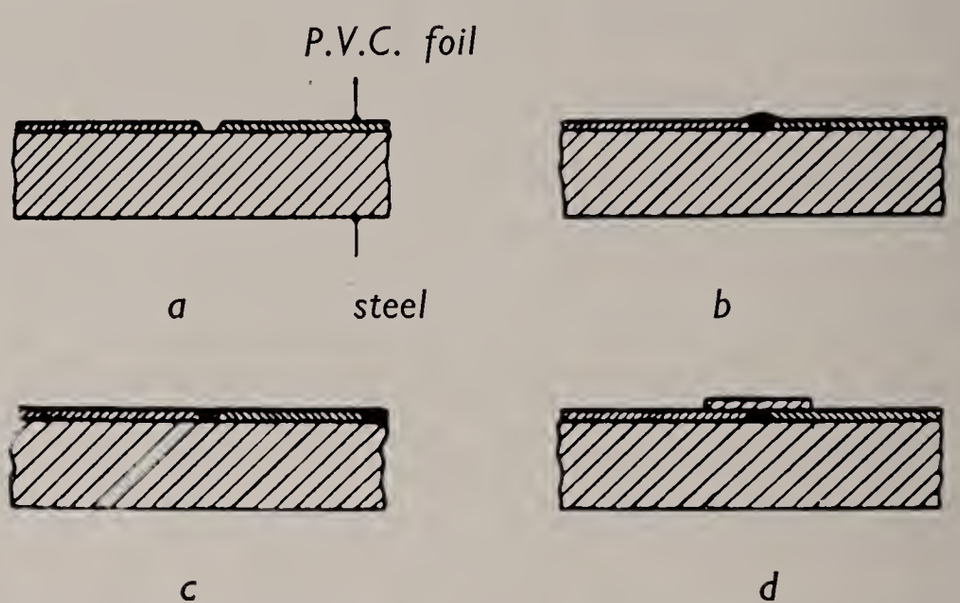


FIG. XIII/4.—Alternative method of lining a tank with rigid P.V.C. foil.

(a). Foils are chamferred prior to welding.

(b) Foils are joined by a single butt-weld.

(c) Crown of weld removed.

(d) Butt-weld covered with P.V.C. strip applied by gas welding.

Testing

A proper inspection and testing by means of a high frequency spark tester should follow the lining operation. Testing should also take place whenever a tank lined with rigid P.V.C. foil has been moved as the stresses caused in transport may be responsible for cracks. All welded seams should be gone over very carefully with the spark tester and it is advantageous to test the butt-welds before they are overwelded with a strip.

Repairs

Unsound parts can be patched up with P.V.C. foil after cleaning the vicinity of the faulty section with methylene chloride and brushing over the area with bonding solution. The cement has then to be degassed and the P.V.C. patch is put in its place after coating with PCA.20 solution.

Larger defective parts cannot be repaired by this method and should be cut out with a heated knife; the cement underneath is then removed by scraping and washing with methylene chloride and a new coat of P.C.10 solution applied. A patch of P.V.C. foil at least 1 in. larger than the hole is then cut and applied. A weld with $\frac{1}{16}$ in. P.V.C. filler rod is then laid round the circumference of the patch.

Air bubbles trapped between the metallic shell of the container and the foil may be troublesome. They can be released by drilling a hole of approximately $\frac{1}{4}$ in. into the foil so that the air can escape. The area around the loose part is then warmed up slightly and the P.V.C. sheet pressed firmly against the metal; the hole is finally covered by a P.V.C. patch. Loose parts of the lining can easily be recognized by tapping.

Lining of wood and concrete vats

The lining technique for wooden and concrete vats differs considerably from that used for metallic vessels as heat cannot be applied from the outside. Bonding in this case is not achieved by the action of heat but depends entirely on the bonding properties of the cement. In Germany a cement of the type P.C.13.A.M. or P.C.D.13 is employed for this purpose but most other types of P.V.C. cements will be suitable provided certain precautions are taken. It should be remembered that most P.V.C. cements are based on a volatile solvent and difficulties will be encountered unless the material of which the vat is made is somewhat porous. This is of special importance in the case of concrete vats.

Green or unseasoned wood has a tendency to shrink and this may lead to warping and cracking; the P.V.C. foil used for lining obviously would not shrink to the same degree and in the same manner. To avoid trouble in this direction, only well seasoned wood should be used. The wood used should be free from resins and knots as these will come out in time and damage the P.V.C. foil. Pitch pine and most types of fir contain a fair amount of resin and they do not therefore permit proper adhesion of the cement; beech and plywood are generally preferred. Vats made of highly resinous wood can be prepared for lining by nailing on plywood sheets of approximately $\frac{1}{4}$ in. thickness.

Concrete vats should be suitably designed and built to allow proper lining.

Reinforced concrete is less liable to cracks and shrinkages. The surface of the concrete should be rendered with a special type of plaster approximately $\frac{3}{4}$ in. thick. The composition of the plaster has some bearing on the subsequent bonding operation, for instance, it should be free from lime and practice has proved that a plaster containing one part of concrete to three parts of sand gives best results. The plaster is applied by a small board (and not by trowels) care being

taken to produce a somewhat roughened surface. This surface can easily be roughened further with a carborundum disc after drying.

Three coats of P.C.13.A.M. cement are applied to the perfectly dry inside of the wood or concrete container. The first two coats are applied the day before lining is to take place with an interval of approximately one hour between the first and second coat; a third coat precedes the actual lining operation by only a very short time and it is left to the operator to judge when the last coat is just ready for the lining operation, i.e. it should no longer be tacky.

P.V.C. foil is brushed with P.C.A.20 solution on one side and heated up with a soft flame from the uncoated side and then pressed into position. The foil should be applied in the direction of calendering and it is advantageous to preshrink the foil before using it for lining purposes.

Jointing by overlapping or overwelding as recommended for steel tanks finishes off the lining operation, but several days should elapse before the welding operation takes place to enable the solvents to penetrate into the wood or the concrete and to volatilize.

Wood or concrete vats lined with P.V.C. foil can be put into use immediately after lining provided the liquids contained in them are cold. In cases where warm liquids will be stored, an interval of approximately two to three weeks should elapse before they are taken into operation.

Limitations of linings made from P.V.C. foil

Linings made from P.V.C. foils should, in general, not be employed for operations involving temperatures exceeding 90° F. (50° C.). Short time use at high temperatures up to 70° C. is however permissible. At temperatures around −10° C. P.V.C. foil becomes rather brittle and may crack.

The abrasion resistance of P.V.C. foil is approximately that of copper. Linings made from rigid P.V.C. foil may therefore be used for tanks equipped with mechanical stirrers. Special care should be taken during any cleaning operations as P.V.C. foil is much more liable to damage by metal tools, nailed boots and step ledders than is metal.

Lining of tanks and vats with laminated P.V.C. sheets

Laminated P.V.C. sheets of $\frac{3}{16}$ in. to $\frac{3}{8}$ in. thickness, (one third rigid unplasticized—two thirds plasticized) see page 46, can be used with advantage to line steel tanks and wooden or concrete vats. The plasticized part of the laminated sheet is stuck to the shell of the tank or vat by means of a suitable cement and the joints are subsequently welded with $\frac{1}{8}$ in. P.V.C. filler rod. This type of lining is more flexible than a lining made entirely from rigid P.V.C. and does not fracture

easily under impact; the unplasticized side of the laminate, i.e., the part of the lining which is in contact with the liquid, provides full corrosion resistance equal to that of unplasticized, rigid P.V.C. Vessels of irregular shape are, however, difficult to line by this method as the relatively thick sheet cannot always be made to follow the somewhat complicated contours; this method is a compromise rather than a solution to a complex problem.

Loose linings made from rigid P.V.C. sheets

Tanks and vats which have to stand up to severe service conditions (high temperatures and agitation) should be provided with an adherent lining and not with loose inserts as owing to the considerable expansion or contraction of P.V.C. the loose liner will not fit the supporting shell unless special precautions are taken.

Loose liners vary in thickness from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. Smaller vessels can be lined with a pre-fabricated liner which is then inserted on site; it is rather difficult to specify limits but in general, vessels up to a capacity of approximately 100 gallons can be lined by this method.

Vessels larger than this should be lined with P.V.C. sheets which are fixed to the outer shell by rivets or anchoring screws, the heads of which are protected with hemispherical covers, pressed from rigid P.V.C. sheets and welded to the sheets. This prevents excessive movement of the sheets when subjected to expansion or contraction (see Fig. XIII/5). The insertion of expansion pieces (extruded or cut from sheet) is another method to overcome expansion or contraction.

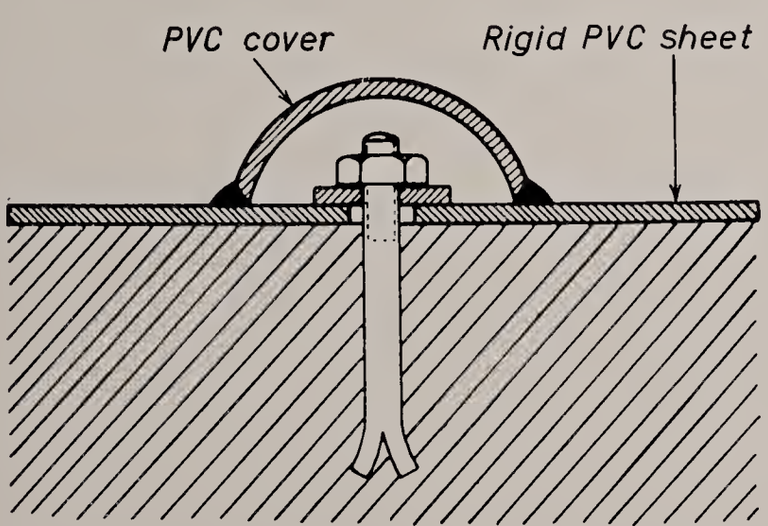


FIG. XIII/5.—Anchoring of rigid P.V.C. linings for large vats.

The lining of very large brick or concrete containers raises special problems; loose linings in $\frac{1}{8}$ in or $\frac{3}{16}$ in. thick materials are applied. The corners are rendered with concrete or plaster, see Fig. XIII/6, so that the P.V.C. lining can be bent—thus avoiding sharp corners. The

individual panels are then fixed to the outer shell by anchoring screws (see Fig. XIII/5).

A great deal of experience and good workmanship is required in order to achieve success in lining large tanks with rigid P.V.C. Figs. XIII/7, XIII/8, XIII/9 and XIII/10 are good examples of large linings which have given satisfaction under severe service conditions.

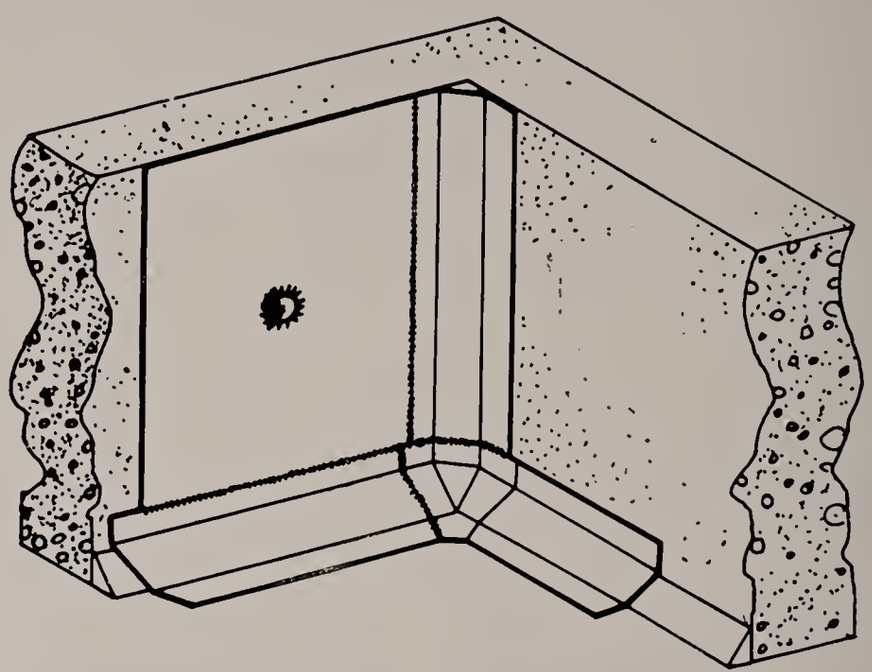


Fig. XIII/6.—Corner piece of a loose rigid P.V.C. lining for a large concrete vat.

Self-supporting Tanks and Containers

Self-supporting tanks and containers fabricated from rigid P.V.C. sheet have become more popular in recent times. Improved fabrication techniques and new materials, for instance, high-impact P.V.C. and metal reinforced laminates, are the main developments leading to these constructions.

Fig. XIII/11 shows a large tank fabricated from corrugated P.V.C. sections, Fig. XIII/12 a rigid P.V.C. reaction vessel with steel reinforcements.

Lining of Tanks and Vats with Plasticized Polyvinyl Chloride

The lining of steel tanks—concrete and wooden vats—with plasticized P.V.C. is a very useful technique, the value of which is not always fully appreciated.

It is a relatively quick and easy process as soon as the operator becomes accustomed to it; the cost of the raw material is much higher than that of thin unplasticized P.V.C., but the saving in labour is considerable, which accounts for the widespread use of this process in countries where labour is relatively expensive.

Experienced workmen will line up to 150 sq. ft. in an eight-hour shift, which is approximately four to five times the area that could be lined when using rigid polyvinyl chloride sheet. Most of the saving

FIG. XIII/7.—One of four mild steel tanks for sulphuric acid factory lined with 0·040 in. rigid P.V.C. sheet. Dimensions of tanks: 12 ft. diameter by 20 ft. high. The lining serves as a membrane between the steel tank and the brick covering. Working temperature 175° F. (80° C.).

in labour is due to the fact that heating of the steel shell is unnecessary as the lining process can be carried out without the application of heat.

The lining of concrete and wooden vats with rigid polyvinyl chloride is, of course, carried out in the cold but the preparation and the rendering of the surfaces to be lined is a lengthy process whilst for the lining of these surfaces with plasticized P.V.C. very much less is required in the way of preparation.

Fig. XIII/8.—Manhole of steel tank shown in Fig. XIII/7.

Techniques for the lining of steel tanks with plasticized P.V.C. sheet have been known for many years, but somehow statements in earlier German publications pointing out that plasticized P.V.C. would, in time, become brittle, due to the loss of plasticizer, has been taken too literally and this is probably the reason why very little lining with plasticized P.V.C. has so far been carried out in Europe.

The position in American and in Canada is different. Plasticized P.V.C. has been used there for tank linings since 1942 and to-day most of the plating tanks in America and Canada are lined with this material. Some of these have now been in continuous use for over ten years and

are still in excellent condition. This is apparently due to special plasticizers employed (plasticizers which do not leach out as easily as some of the plasticisers used in Europe) but is also due to the fact that the P.V.C. sheet employed is reasonably thick.

Plasticizer losses by leaching or by evaporation cause formation of an unplasticized P.V.C. film or layer (hardened skin) on the outside. This skin stops effectively the further migration of the plasticizer. It is therefore understandable that in cases where the plasticized P.V.C. sheet is reasonably thin, very little plasticized material will be left under the hardened surface, whilst in the case of relatively thick sheets sufficient plasticized material is left under the protective top layer to move with the tank—expanding or contracting.

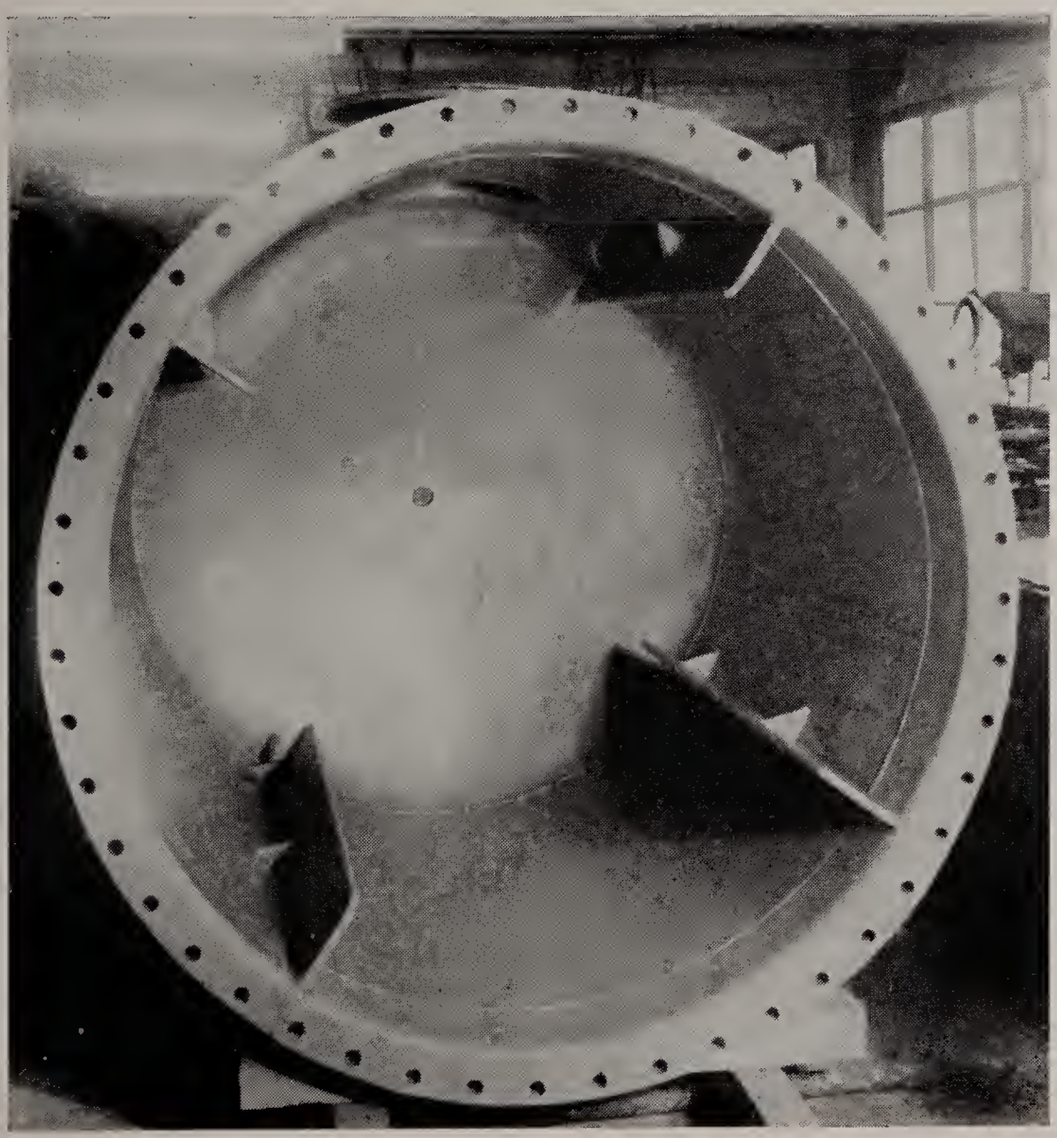


FIG. XIII/9.—Mild steel reaction vessel lined with 0·080 in. thick rigid P.V.C. Dimensions: 6 ft. 6 in. diameter × 6 ft. high.

Earlier attempts to line tanks with plasticized sheet in Germany were unsuccessful because the Germans used very thin sheet ($\frac{1}{32}$ in. or thereabouts) which hardened right through in due course, causing failure of the lining. American linings are at least $\frac{3}{32}$ in. thick and

therefore remain elastic for a long time although the surface hardens up very quickly.

Plasticized P.V.C. does not age very quickly, neither is it susceptible to degradation by oxidizing agents and it is from this point of view that it is much more satisfactory than rubber or ebonite. It also has greater elongation than rigid P.V.C. sheet and adheres very well to the supporting shell. Rigid P.V.C. has a thermal expansion approximately seven times that of steel and it is, therefore, rather difficult to line tanks to be used later on at elevated temperatures as the difference in thermal expansion causes stresses on the lining which in time will peel off or buckle. This trouble is considerably less frequent with relatively thin, rigid P.V.C. foil, but the latter is not always free from pinholes.

FIG. XIII/10.—Two mild steel tanks of 18 ft. diameter lined with $\frac{3}{16}$ in. thick rigid P.V.C. sheets. These tanks hold a viscose-spinning solution. Working temperature: 130° F. (54° C.).

It is a further advantage of this process that tanks lined with plasticized P.V.C. can be used up to a temperature of 185° F. (87° C.).

The practice of lining tanks with plasticized P.V.C. sheet in the United States and Canada is becoming very popular and in many instances plasticized P.V.C. linings are used in America where rubber linings are used in Europe.

A well-known American firm supplying electro-plating equipment

disclosed, some years ago, that their annual turnover in plasticized P.V.C. linings exceeded one million dollars.

There is no reason why this technique should not become equally popular in other parts of the world.

Specification for steel tanks to be lined with plasticized P.V.C.

Almost any steel tank or container can be lined with plasticized P.V.C. sheet provided it is sufficiently wide to enable the operator to work inside it without obstruction. Rectangular and cylindrical open tanks are generally preferred, but large road tankers can also be lined using this technique.

FIG. XIII/11.—P.V.C. tank with steel reinforcements. Note the corrugations in the P.V.C. sheets—providing additional strength.

The tanks and vats should be fabricated in accordance with standard commercial practice. Rectangular tanks of the open top type should be reinforced to provide adequate structural strength and to prevent bulging. In the case of sectional tanks which are to be bolted together, care should be taken that corners are square and smooth; the sections should fit tightly when bolted together. Reasonable care should also be taken to prevent distortion or warping in transit. Parts not to be covered with P.V.C. should be marked to avoid mistakes.

In the case of dished heads, care must be taken to eliminate all wrinkles from the deep drawing or pressing operation, especially if

these are flanged together. All joints should be continuously welded and the welds should be smooth and free from pinholes and high spots. Welds on the inside of the tank should be ground off, corners should be bent or ground to a minimum radius of $\frac{1}{8}$ in. All body seams should be butt-welded unless otherwise stated. The actual location of inlets, outlets, etc., should be clearly shown on the drawing; flanges should be parallel with the tank so that the pipe lines will leave the tank at right angles to the surface unless specific reasons demand a different angle.

FIG. XIII/12.—Rigid P.V.C. reaction chamber for a pharmaceutical factory.

All dimensions quoted on the drawing should refer to the inside measurements of the tank with tolerances of $\pm\frac{1}{8}$ in. on dimensions up to 24 in.; for dimensions over 24 in. a tolerance of $\pm\frac{1}{4}$ in. is permissible. Details referring to the welding and fabrication of steel tanks to be lined with plasticized polyvinyl chloride are shown in Figures XIII/1a, b, c, d and e.

Preparation of tanks to be lined with plasticized polyvinyl chloride

It is essential to sand blast or grit blast the surfaces of the tanks to be lined in order to remove rust, grease or paint which would prevent the cement from sticking satisfactorily. The pitting of the surface caused by the blasting operation provides a proper key for subsequent bonding. The blasting operation should be carried out almost immediately before lining as the clean surfaces have a tendency to rust, especially in humid atmospheres when the tanks are moved

from one shop to another. Shot blasting is preferred to sand blasting as the use of sand may cause silicosis of the operator.

There is no necessity to go into details regarding the blasting of the tanks as this is very similar to the preparation of steel tanks to be lined with rubber or ebonite; there are a great many different types of blasting equipment available, all of which have their advantages and disadvantages. The *Vacu-Blast* equipment shown in Fig. XIII/13 is portable, readily installed, easily handled and operated entirely by compressed air. Various interchangeable blast heads can be supplied with this equipment, its operation is almost dustless. Smaller parts can be descaled and made rust-free by means of compressed air Multipoint Descaling Pistols.

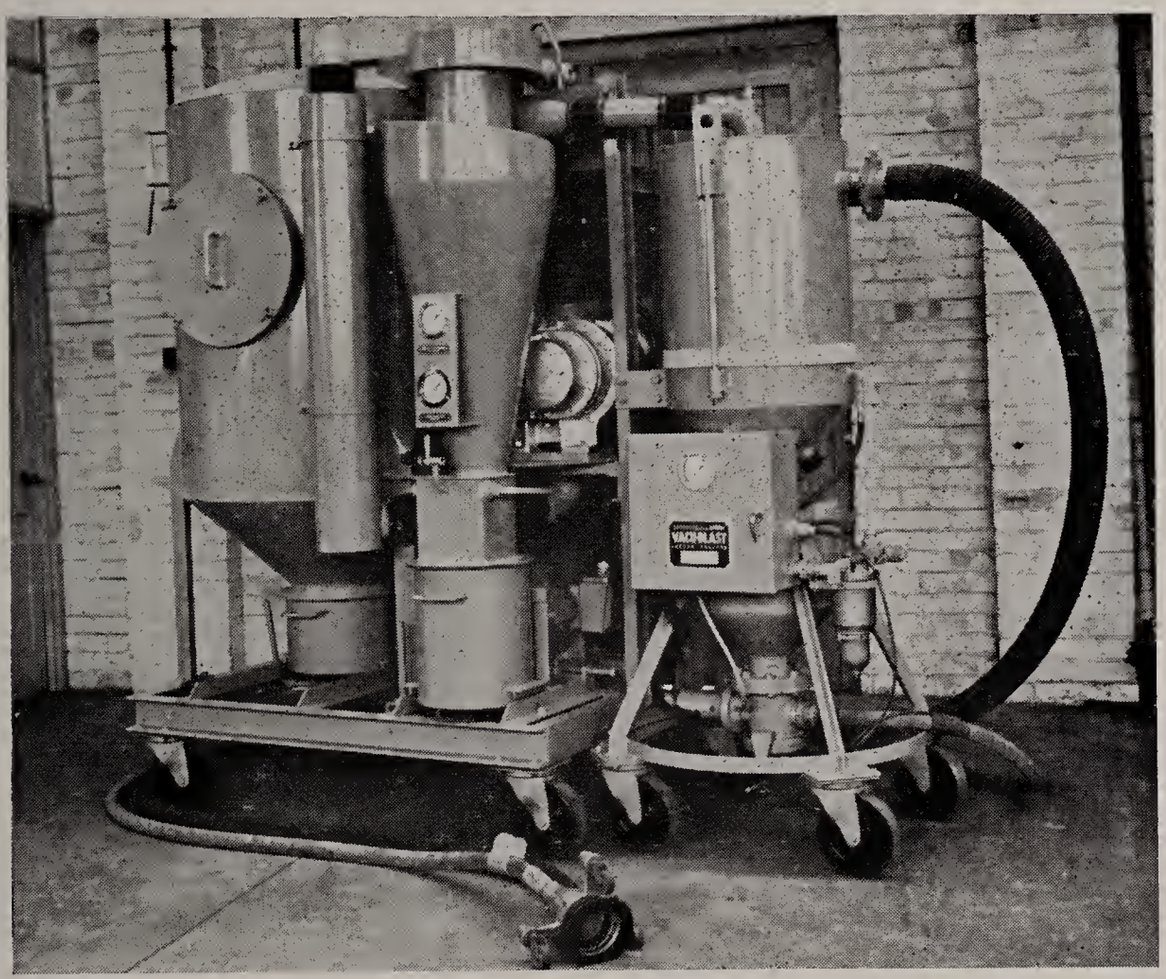


FIG. XIII/13.—Vacu-blast equipment for shot-blasting of mild steel tanks.

Equipment for lining

The following equipment is required for lining tanks with plasticized P.V.C.:—

One welding torch.

Approximately 50 ft. of rubber tubing in at least two lengths of 25 ft. each.

One or two manometers for regulating the welding gas.

A pair of 12 in. shears.
Screwdrivers.
Pliers.
4 in. paint brushes.
2 in. paint brushes.
Masking tape.
Extension cord.
Steel tape.
Wire brushes.
Infra-red heating unit to pre-heat the P.V.C. sheets.
One spark tester for testing.
Rags.

The customary hot-air welding torch used for the welding of P.V.C. and polythene is quite suitable but slow in operation and in order to achieve quicker results hydrogen torches are recommended.

The first hydrogen torches for the welding of plasticized P.V.C. were developed by the Udylite Corporation in the United States and are covered by U.S. Patent No. 2,372,737. The Udylite torch consists of a cylindrical steel shell with two tubular inlets, one for hydrogen and one for compressed air. It also carries a removable nozzle on the tip. The torch is approximately 8 in. long and light in weight.

Two manometers are required to adjust the supply of hydrogen and compressed air to a reasonably fine degree. A sufficient footage of rubber hose to connect the hydrogen cylinder and the compressed air to the torch as well as to the manometers is also needed. The manometer for measuring the pressure of the compressed air is filled with mercury, the hydrogen manometer with fluorescein solution.

Pressure requirements for both gases depend on the welding speed, thickness of the material to be welded, etc., and have therefore to be established on the spot. It could, however, be mentioned for general guidance that the pressure for hydrogen should be approximately 10 in. (water), that for compressed air approximately 5 in. (mercury).

The operation of the torch is quite simple. The nozzle of the torch has to be removed by unscrewing. A restricted flow of hydrogen is then allowed to pass through the torch and the hydrogen is lit by an open flame; it will ignite with a reasonably sharp sound. The supply of air should then be turned on slowly and both air and hydrogen supply should be adjusted until the flame is no longer visible outside the mouth of the torch, i.e. the flame should burn inside the cylindrical shell. When this is achieved, the nozzle can be screwed on by means of a pair of pliers.

The welder should hold the torch at the rear end as shown in Fig. XIII/14. He has to work at a high speed to avoid overheating and burning of the material. The torch remains reasonably cool and can

be handled safely without wearing protective gloves. Torches similar to the Udylite torch are now available in Europe.

Another American torch suitable for welding plasticized P.V.C. linings, the Tuf-Bond sealing gun, is electrically heated. It is supplied with a range of differently shaped nozzles, for instance, L-shaped nozzles for the welding of triangular filler rod. A built-in electric bulb lights the working area and facilitates the control of the welding operation.

Rollers

Wooden or steel rollers are employed to press the flat or triangular

FIG. XIII/14.—Lining of a steel tank with plasticized P.V.C. sheet. (Application of sealing strip using a hydrogen torch.)

strip into position while it is still soft and pliable; in some cases flattening rollers are attached to the torch so that welding and pressing can be carried out at one and the same time.

Brushes

Soft hair brushes 2 in. and 4 in. in width are best for applying the cement. Smaller brushes require more effort whilst those wider than 4 in. are more difficult to use for any length of time. The brushes should be cleaned in a suitable solvent after each operation as hard brushes do not distribute the cement satisfactorily.

Infra-red heaters

Plasticized P.V.C. sheet is not always sufficiently pliable to follow the contours of the vessels or containers to be lined. The softness of the material depends on the compound used and, of course, on the amount and type of plasticizer employed. It is, therefore, good practice to use infra-red lamps for the pre-heating and softening of the sheet prior to lining. These infra-red lamps are housed in a frame and there should be a sufficient number of them to cover at least one square yard with their radiation. It is an advantage to arrange the frame in such a way that it can be swivelled into position, i.e. turned 90°. Alternatively, the whole arrangement should be capable of being lowered or raised. Care should be taken to keep the focus of all the infra-red lamps at the same level, at the right distance from the sheets.

A more practical arrangement is the following. Approximately 25 of these infra-red lamps are arranged in a frame measuring approximately one square yard. The frame is attached to two overhead rails erected over a work bench measuring approximately 12 ft. × 4 ft. The P.V.C. sheet, in the form of rolls on a wooden roller going through the centre, is fixed to an attachment on the right-hand side of the work bench so that it can be drawn freely over the bench. In order to operate this equipment procedure is as follows: The first square yard is drawn on to the bench and the cement brushed on covering the surface of the sheet. The sheet is then moved along 3 ft. so that one further square yard goes on to the bench. The infra-red frame is then switched on and drawn into position, i.e. to pre-heat the first square yard covered. The excess solvent evaporates and the sheet becomes soft through pre-heating. This operation is continued until the full length of the sheet is coated and pre-heated. A transverse cut is then made with a sharp knife and the sheet is then transferred to the surface to be lined.

P.V.C. sheet

Opinions about the methods of manufacturing plasticized P.V.C. sheet are somewhat divided; most users prefer rotocured sheets which

are available in rolls up to 60 ft. length and up to 4 ft. in width. Roto-cured sheets are much more economical in use than sheets produced on ordinary multi-daylight presses; the latter are necessarily of limited size (approximately 8 ft. × 4 ft.) and losses due to off-cuts are rather high.

The surface of the sheets should be matt (at least on the side to be bonded to steel), as highly polished surfaces or glossy surfaces reduce adhesion. Check tests should be made to make certain that the sheets do not delaminate under the influence of heat. Insufficient heat and lack of pressure during the manufacturing process yields sheets which are prone to delamination.

The thickness of the sheets varies according to service conditions; $\frac{3}{32}$ in. thick sheets meet most requirements but the bottom lining of electro-plating tanks should be at least $\frac{1}{4}$ in. thick, so that sharply pointed articles or anodes accidentally dropped cannot cut through the lining.

The tensile strength of the sheets is approximately 2,000–3,000 p.s.i., elongation varies between 300 and 400 per cent. The hardness depends mainly on the plasticizer content but is in general around 80–90° shore 'A'.

It is quite natural that manufacturers keep the composition of their compounds and their sheets as a trade secret and it is sufficient to say here that all these sheets contain P.V.C., a stabilizer, plasticizer (approximately 40 per cent.) and carbon black (approximately 1 per cent.). Good stabilization is necessary to avoid burning or blistering of the sheet during welding.

Most of the sheets used for lining are black in colour, but for the lining of tanks to contain food-stuffs white sheet is recommended. In this case non-toxic plasticizers must be employed and the carbon black is replaced by TiO_2. The stabilizer too must be non-toxic.

In the United States there are at least three different brands of plasticized P.V.C. sheet available for the lining of tanks. The oldest, known as Koroseal, is manufactured by the B.F. Goodrich Company. Another brand, also used extensively, is Tygon, made by the U.S. Stoneware Company. More recently Kaykor Industries Inc., have brought out a plasticized P.V.C. sheet under the trade name of Vyflex L–10.

Equivalent British materials are manufactured by BX Plastics Ltd., under the name of Velbex and by the Bakelite Company Limited under the name of Vybak VB.185 and DVB.237.

The Germans manufacture Mipolam (Dynamit A.G.) and Igelit in the Eastern zone of Germany for the same purpose.

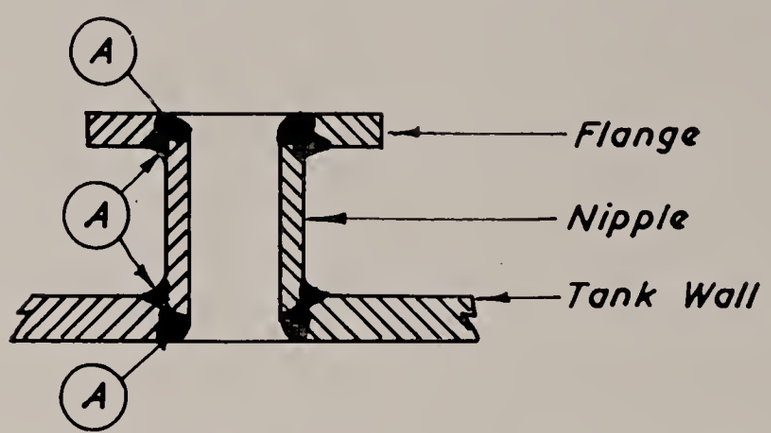
Sealing strips

The abutting edges of a lining are over-welded with flat or profiled

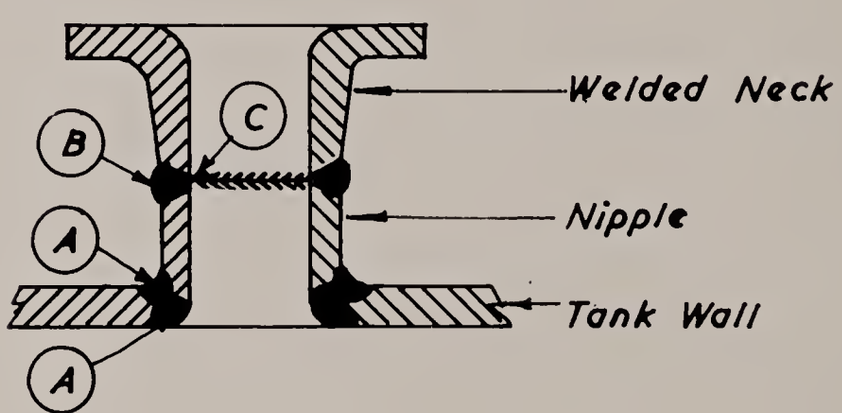
sealing strips; corners are sealed with triangular strips. All these are extruded from the same type of compound which is used for the manufacture of the sheets—to make certain that the welds are of the same chemical resistance as the lining.

Tubing

Most tanks carry flanged inlets and outlets and obviously these attachments have to be lined as well. The easiest way to line these is by means of inserted plasticized P.V.C. tubing which is obtainable in



Flanged outlet on tanks and covers



Flanged outlet on tanks ('Taylor' welding neck)

Pad outlet

FIG. XIII/15.—Specifications for metal welds on outlets:

(*A*) Should properly penetrate, i.e. welds from both sides should meet thus eliminating air pockets. Weld deposit should be pressed and ground smooth before lining.
(*B*) To be deposited in beads not exceeding $\frac{3}{16}$ in. The inside should then be gouged out, and slag and scale should be removed.
(*C*) To be welded from the inside; subsequent pressing and removal of surplus weld metal necessary.
(*D*) Same as (*A*); penetration not essential.
(*E*) Bevels should equal the thickness of the metal from which the tank is constructed. Pressing and grinding of inner weld required.

extruded form in standard widths of 1 in., $1\frac{1}{4}$ in., $1\frac{1}{2}$ in., $1\frac{3}{4}$ in., and 2 in. For specifications of inlets and outlets see Fig. XIII/15.

Cements used for bonding of plasticized P.V.C. to steel

The success of bonding and the lining process in general depends on the choice of suitable cements. Most of the cements available in Europe are not of the same excellent quality as those available in America. Details, therefore, are given of American cements with a short reference to European types in the hope that the latter will be improved in time and become similar in quality to American cements.

A typical cement for bonding plasticized P.V.C. sheet to steel is U.S. Stoneware Tygonite which consists of two components, Tygonite 10A and Tygonite 10B. Tygonite 10A is a steel primer, Tygonite 10B is a vinyl bonding cement. Both these cements are supplied in liquid form and have a tendency to thicken and to harden up on the shelf. They can be revived by the addition of suitable solvents such as methyl-ethyl ketone. Kaykor Industries suggest the use of their Vyflex SP–100 steel primer together with their Vyflex VP–200 vinyl primer and their Vyflex BC.300 bonding cement. These, too, can be revived by the addition of suitable solvents.

Boscolite primer No. 9252 and Boscolite adhesive No. 1430 from the B.B. Chemicals Ltd. in England are reasonably satisfactory.

All vinyl cements are highly inflammable and suitable precautions should be taken for their transport and storage.

Lining

It is assumed that the tank has been supplied to the lining shop in sand-blasted or shot-blasted condition and that the general conditions for preparing the tank have been complied with (see details for the fabrication of steel tanks to be lined with plasticized P.V.C. pp. 146, 147).

The operator should at first prepare a sketch to ascertain the correct size of the individual pieces prior to cutting and also plan the proper sequence of the individual operations.

In the case of rectangular tanks, the individual sheets should be cut to cover one side only—with an allowance of at least $\frac{1}{4}$ in. for shrinkage. No attempt should be made to fold sheets into square corners or into rounded corners with a heavy weld inside. By doing this the danger of trapping air in the corners (underneath the lining) is avoided.

The inside of the steel tank is then brushed neatly and uniformly with the priming solution (Tygonite 10A, Vyflex SP–100, Boscolite 9252 or the like) and left to dry for at least six hours.

In the meantime the P.V.C. sheets can be prepared for lining. They should be wiped clean with a rag soaked in methyl-ethyl ketone and are then brushed on the side to be bonded with the bonding cement (Tygonite 10B, Vyflex VP–200, Boscolite adhesive 1430 or any other

suitable cement). The sheets are then left to dry for approximately one hour, when a further coat of adhesive is brushed on. Heat is then applied from an infra-red heater to render the sheets soft and pliable and to evaporate part of the solvent in the adhesive. (Heating for approximately 2 minutes is usually sufficient to achieve the right degree of flexibility.)

FIG. XIII/16.—Lining of a tank with plasticized P.V.C. sheet. (Application of the sheet.)

Whilst this is done another operator applies one or two coats of adhesive (Tygonite 10B or the like) to the primed steel surface allowing at least one hour before applying the second coat.

The sheets are then carefully transferred to the tank under suitable precautions to prevent dust, dirt, etc., settling on the freshly painted surfaces. It is an advantage to start the lining operation from the top of the container, i.e. to let the sheets hang down (see Fig. XIII/16), as it is much more difficult to line from the bottom upwards. The sheets should run parallel to the side of the tank; the technique for doing this successfully is very similar to the one employed for the hanging of wall-paper and requires some practice. The sheets are pressed firmly against the surface of the tank by carrying out a circular movement

with the palm of the right hand; this is perhaps the most difficult stage of the whole lining operation—as the sheets have to be stuck to the tank at some speed, i.e. whilst they are still warm and pliable. Air bubbles caused by trapping air between the walls of the tank and the P.V.C. sheets must be avoided at all costs as they increase in size when the temperature of the liquid in the tank is raised, causing separation of the lining from the tank. Some of the best cements bond so well that it is most difficult to peel the sheets off after attaching them to the steel and peeling under considerable force may lead to destruction of the sheets.

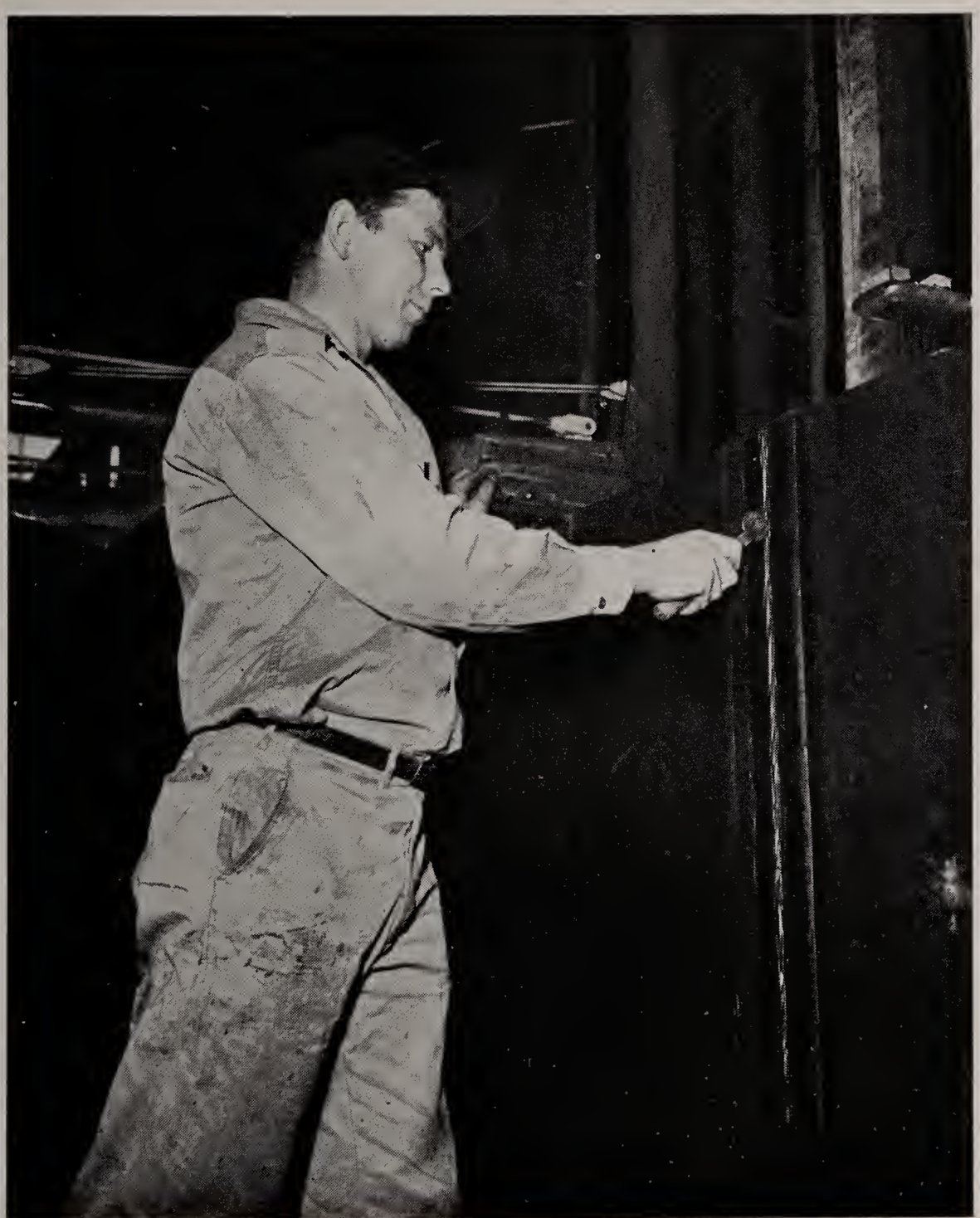


FIG. XIII/17.—Lining of a steel tank with plasticized P.V.C. sheet. (Consolidating the weld by means of a pressure roller.)

Welding

Sealing strips are welded over abutting edges (butt-welds) or in corners (fillet-welds). Fig. XIII/14 illustrates the procedure. The sealing strip is pressed against the surfaces to be over-welded whilst the full blast of hot air or steam mixed with air (in the case of hydrogen torches) is simultaneously directed against the surfaces of the P.V.C. sheet and the sealing strip. The operator has to proceed with considerable speed to avoid blistering or burning of the material and moves the torch up and down to prevent overheating of a particular section. The speed of welding is very much greater than in the case of rigid P.V.C. or polythene and varies from 2 ft. to 3 ft. per minute. The welding of corner strips and triangular sections can be carried out in a similar way but this is slightly more difficult than welding with flat strip. A follow-up roller is used for pressing the strip into position, see Fig. XIII/17.

Welding in the bottom corners is difficult, and it is, therefore, suggested that the ends be pointed in the corners and to lead the corner strips in from all three sides and finally to make the welds smooth using a suitable rolling tool.

Open tanks or containers should have a flange on the top so that the P.V.C. sheet can be drawn over it and down the sides for approximately 6 in. This facilitates the work of the operator as the sheets shrink on cooling and tighten up; any unevenness (slight wrinkles, etc.) gradually disappears. No extra charge is made for the lining of this flange. All welds should be tested with a spark tester set for 8,000 volts.

Some firms polish the finished tank lining with an open flame or by going over it with a special welding torch so that the lining becomes highly polished. This operation greatly improves the appearance of the lining but is somewhat dangerous unless great care is taken as air inclusions will expand when heat is applied thus causing the sheets to separate from the steel shell. The uncoated surfaces of the lined tank are then sprayed or brushed over with a protective layer, preferably with a vinyl base lacquer, to prevent corrosion of the exposed metal surfaces when in contact with fumes or when the contents of the tank are accidentally spilt.

In the case of very large tanks, used for pickling, it is customary to apply an acid resisting brick lining over the plasticized polyvinyl chloride lining, which thus becomes a membrane.

Repairs

It is quite easy to repair damaged linings in plasticized polyvinyl chloride by cutting out the faulty parts, preparing a piece of P.V.C. sheet of exactly the same dimensions, and cementing it into position, subsequently over-welding the edges by the method described above. It is, however, essential that repairs are carried out as soon as the

damage has been observed, as the corrosive solution will attack the steel shell underneath and may eat its way in, thus ruining the tank.

Blisters

Small blisters, even in great numbers, need not cause alarm. If they get larger, however, the particular section of the lining where they occur should be replaced. Larger blisters have to be eliminated either by drilling through the steel wall to release the air or by puncturing the lining, releasing the air, heating up the surround of the hole and afterwards pressing down the softened P.V.C. sheet to close the hole.

Costing

It is general practice in America to quote for the lining of tanks and vats with polyvinyl chloride according to the area covered, calculated from the inside dimensions of the tanks. Usually, no charge is made for covering the top angle or channel provided it is not larger than 3 in. If the latter is the case, an additional amount is charged. The lining is, in most cases, over the top and underneath the horizontal leg and approximately 3 in. further down on the tank. As a general rule it can be said that the larger the tank the cheaper the lining; in most cases the applicator bases his calculations on a minimum area of 75 square feet. For tanks having a surface area of less than 75 square feet an additional charge per square foot is made. The applicator makes also, additional charges for the lining of flanges, manholes, etc., and for removing old linings.

It is always an advantage to line tanks at the premises of a firm specializing in this technique, but lining on site can also be carried at a somewhat higher rate.

Typical examples of lining tanks with plasticized P.V.C.

The following two examples of lining operations in two American works are given to indicate the time taken and material requirements for lining two mild steel tanks. (Relatively small tanks take proportionally longer to line than large tanks.)

Shop No. 1.

Dimensions of tank: 7 ft. 0 in. × 2 ft. 6 in. × 3 ft. 0 in. = 74·5 square feet.
Material applied: P.V.C. sheet $\frac{3}{32}$ in.
Cement: 1 gallon.
Welding strip: 35 feet.
Labour, not including sandblasting=15 hours.

Shop No. 2

Dimensions of tank: 7 ft. 6 in. × 2 ft. 6 in. × 2 ft. 0 in.=66 square feet.
Material applied: P.V.C. sheet $\frac{3}{32}$ in.
Cement: 1 gallon.
Welding strip: 35 feet.
Labour, not including sandblasting=8 hours.

A tank measuring 3 ft. × 3 ft. × 3 ft. can be lined by a skilled welder in approximately 4 hours. The author has once followed the lining of a tank 25 ft. long × 12 ft. in diameter with a partition in the centre. This was done in $3\frac{1}{2}$ days by three men, i.e. the total labour involved amounted to less than 90 hours.

Fig. XII/18 shows a mild steel section lined with plasticized P.V.C. sheet using the methods described in this chapter. Fig. XIII/19 illustrates a large mild steel tank lined with plasticized P.V.C. using the customary hot-air torch for welding.

Fig. XIII/18.—Mild steel trough 10 ft. long × 3 ft. wide × 4 ft. high lined with plasticized P.V.C. sheet.

Lining of concrete vats with plasticized P.V.C.

Lining of concrete vats with plasticized P.V.C. has been practised to a certain extent in Germany and other countries in Europe.

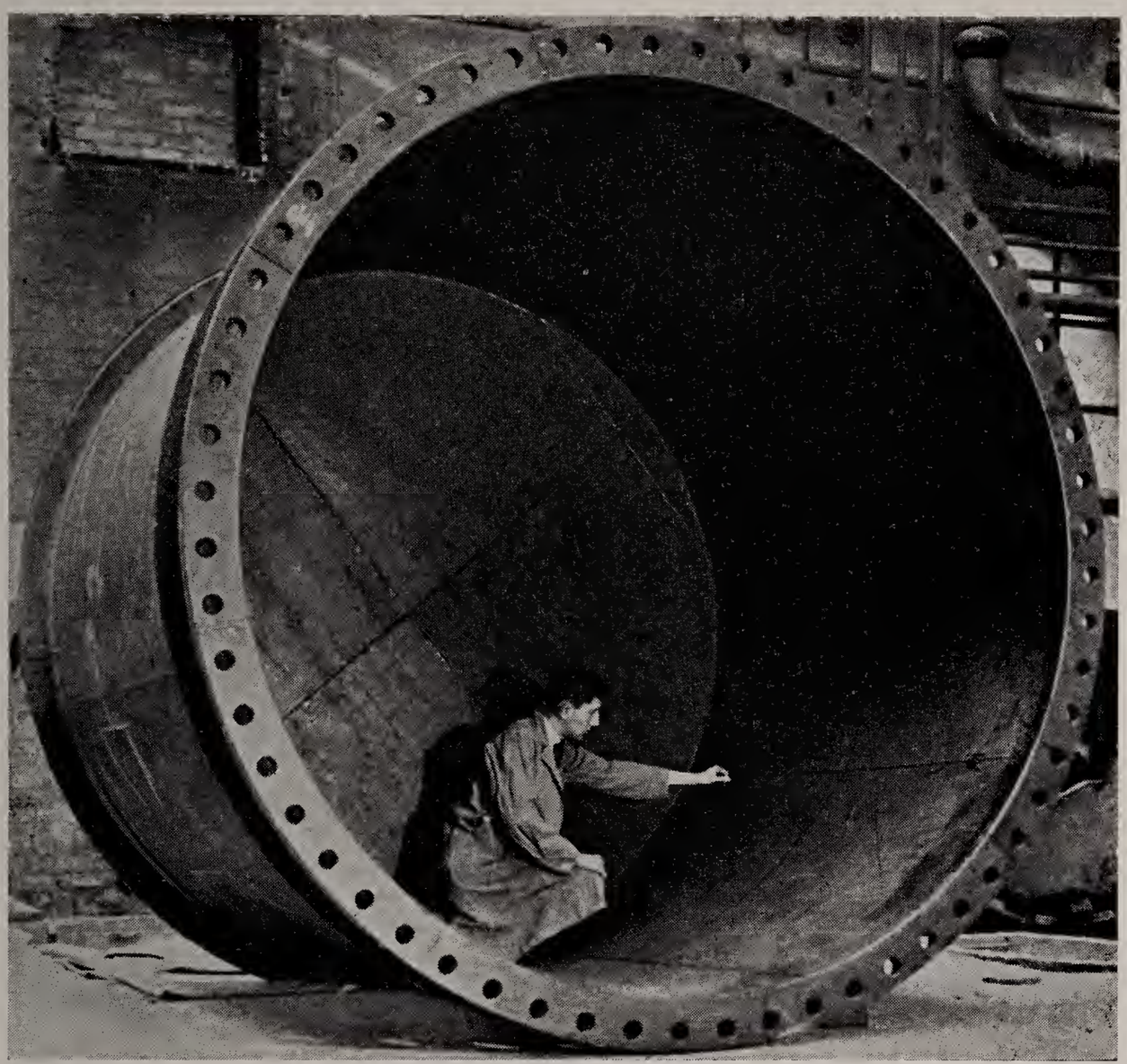


FIG. XIII/19.—Large circular steel tank (9 ft. diameter × 9 ft. high) lined with plasticized P.V.C. sheet.

Preparation of the concrete to be lined

To achieve satisfactory lining of concrete with plasticized P.V.C. it is necessary to render the concrete with a special layer of cement approximately $\frac{3}{4}$ in. thick. It is preferable to apply the rendering cement in two layers of equal thickness. The sand used for preparing the rendering cement should be reasonably fine ($\frac{1}{64}$ in. to $\frac{1}{8}$ in.). A suitable mixture would, for instance, be one part cement and two parts round sand, or alternatively one part cement and three parts of gritty sand. The cement should be applied with a trowel. The top layer should remain reasonably porous so that solvents emanating from the bonding cement can evaporate through the concrete as they obviously

cannot evaporate through the P.V.C. lining. It is, therefore, understandable that a smooth top surface of the tank to be lined is objectionable. All corners should be rounded with a radius of at least $\frac{1}{8}$ in., the radius on outer corners should be even higher.

Once the tank is rendered it should be left to dry out properly; its surface is then roughened by means of an emery wheel to remove heavy grit and uneven parts which protrude. The surfaces to be lined should then be made dust-free (by using a vacuum cleaner) after which the tank is ready for application of the bonding cement.

Bonding

At least three, preferably four, layers of bonding cement P.C.D.13 or P.C.A.20 are required. The first coats should be applied a day or so prior to the actual lining process and the subsequent coats at intervals of one to two hours. The last coat should be applied immediately before the actual lining (20 minutes or so) and remain just tacky. The bonding cement is applied by means of a soft brush and care should be taken to avoid heavy brush marks. Round brushes with a diameter of 2 in. to 3 in. and a bristle length of approximately $1\frac{1}{2}$ in. give best results. Bonding cements, and in particular PCD.13, can cause eczema and protective clothing should be worn by the operator. During the drying of the intermediate layers care should be taken to avoid draught or radiation by the sun.

The amount of cement required varies but is in general, approximately 0·2 lb. per square foot.

Preparation of the P.V.C. sheet

The plasticized P.V.C. sheet used for lining should be rough or slightly corrugated on the bonding side to facilitate bonding. The sheet to be bonded is made dust-free—then two coats of P.C.10 or P.C.D.13 are applied. The second coat can be applied after a drying time of approximately two hours. The sheet is then left to dry for approximately 15 hours, but should not be left for more than 45 hours. The coating of the P.V.C. sheet should coincide with the third application of the bonding cement to the concrete vat. The amount of bonding cement required for coating the P.V.C. sheet is approximately $\frac{1}{4}$ lb. per square foot.

Bonding of the sheet

The soft P.V.C. sheet should be applied while the bonding cement on the concrete is still tacky. The P.V.C. sheet should be slightly preheated from the uncoated side by means of a soft flame so that it becomes soft and pliable. Rubbing with the palm of the hand helps to press the sheet into position, but care should be taken to avoid air bubbles.

The abutting edges should either be over-welded by means of a flat P.V.C. strip or overlapped. Over-lapping is definitely preferable. The welding should be carried out, whenever possible, several days after lining to avoid lifting of the sheet from the concrete.

Concrete vats lined with plasticized P.V.C. can be taken into use soon after the lining has been applied, provided the temperature of the liquid to be stored does not exceed 30° C. In cases where the temperature exceeds 30° C., vats should be left for approximately 2–3 weeks before taking them into use.

It is also possible to line wood with plasticized P.V.C. sheet, but adhesion is not very good owing to the fact that any moisture emanating from the timber will cause formation of bubbles, which will lessen the bond. It goes without saying that the timber used should be properly seasoned so that the vat does not subsequently warp in service.

Plasticized polyvinyl chloride with corrugations or extensions on one side is being used in America for the lining of concrete vats and large bore tubes. The framework for the vat is prepared in timber. The plasticized polyvinyl chloride sheet is then inserted in such a way that the smooth surface of the sheet is in contact with the wooden framework, i.e. the corrugations or extensions protrude into the concrete poured in afterwards. When the concrete sets, the corrugations become firmly locked in it. Concrete containers of very considerable size have been lined in this way. A typical material of this type is T-Lock Amer-Plate produced by the Amercoat Corporation.

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CHAPTER XIV

POLYVINYL CHLORIDE PIPE LINES

by E. A. O. MANGE

Commercial aspects

Amongst the first applications of rigid P.V.C. were pipe lines. Chemical factories of the I. G. Farben Industries concern in Germany installed such lines—mainly for acids and other corrosive liquids, just prior to the last war. Experience gained over a number of years led to the use of rigid P.V.C. for domestic water supplies. These were used for the first time in Germany in 1943. The use of P.V.C. for domestic water supplies has grown steadily in most European countries and reached its peak around 1955; since then it has remained at the same level and has in some cases slightly declined, mainly due to the introduction of polythene which can be installed at slightly cheaper rates. Accurate figures for P.V.C. pipe consumption are difficult to obtain, and most of the figures quoted in various journals and reports are not very reliable. Official figures are, however, available from two countries—Western Germany and Holland.

According to a report in *Chemische Industrie* (International) in June, 1958, 2,700 tons of plastic pipes were consumed in Germany in 1957. This figure comprises both P.V.C. and polythene pipes; about 1,700 tons of these were polythene pipes, and approximately 1,000 tons were P.V.C. Comparing this figure for P.V.C. pipes with Germany's total output of P.V.C., which is approximately 100,000 tons p.a., one can conclude that rigid P.V.C. pipes are not a major production item in that country.

Reports from Holland present a much more encouraging picture. More than 4,000 tons of rigid P.V.C. pipes were produced in 1958 in Dutch factories. The approximate break-up was as follows:

1,000 tons for domestic water supplies
400 tons for gas distribution
1,000 tons for electrical conduits
500 tons for drainage of sewage
600 tons for land drainage
500 tons for miscellaneous applications.

The higher consumption of P.V.C. pipes in Holland (0·88 lb. per head of population as against 0·045 lb. in Germany) is probably due to the

fact that P.V.C. pipes are readily accepted by the Dutch Waterworks Association and other official departments, whilst in Germany, as in most countries, there is still a strong bias towards metallic pipes; lately the opposition to plastic pipes for domestic water supplies has somewhat diminished, for instance, in the United Kingdom, the United States of America and also in Canada; in all these markets, however, polythene pipes are preferred to P.V.C. pipes.

An estimate from American sources (*1*) predicted, that 1,000 miles of 2 in. and 3,000 miles of 4 in. rigid P.V.C. pipes would be installed in 1954 for crude-oil gathering lines; this would have amounted to nearly 16,000 tons of rigid P.V.C. for one particular oilfield alone. Unfortunately, these estimates were far too optimistic and most of the plans envisaged never matured. The only major P.V.C. project reported in 1954 from the United States was a 2 in. line 33 miles long used to carry salt water from petroleum separators. (Total weight estimated 55 tons.)

There should be a greater potential for P.V.C. pipes in the U.S.A. and in Canada than in most other parts of the world because the costs for skilled labour over there are extremely high ($2.50 per hour—without overheads). P.V.C. pipes can be installed at a very much faster rate than steel pipes, especially where suitable fittings for cementing are available; P.V.C. pipes should therefore compete successfully with steel pipes even if their initial price is up to 30 per cent. higher.

Advantages

Rigid P.V.C. pipes offer the following advantages:—

They resist internal and external corrosion and do not need maintenance.

They are light in weight—approx. half the weight of aluminium and about one-fifth of the weight of steel pipes of similar wall thickness.

They are also non-conducting and not subject to electrolytic action. They are non-inflammable.

They are smooth in bore and permit a higher through-put of liquids on account of their reduced resistance to flow. They have excellent resistance to abrasion and are non-toxic.

Disadvantages

P.V.C. pipes are notch sensitive; their impact strength is lower than that of most other plastic materials or metals.

The tensile strength of rigid P.V.C. pipes diminishes rapidly at increasing temperatures, which limits their use to applications involving comparatively low temperatures (not exceeding 150° F. (65° C.)).

Plumbing in rigid P.V.C. on an economic basis calls for standardized

Additional copies of the six page color section between pages 164-165 may be purchased, price $2.25 each, from the publishers.

IX/1. Starting a weld in rigid P.V.C. Preheating of the sheet-setting of the filler rod (under an angle of 90° to the sheet) – simultaneous heating of filler rod and sheet.

IX/2. The filler rod should be bevelled at the starting end to facilitate welding.

IX/3. This filler rod was not bevelled–bad start–the filler rod lifts up.

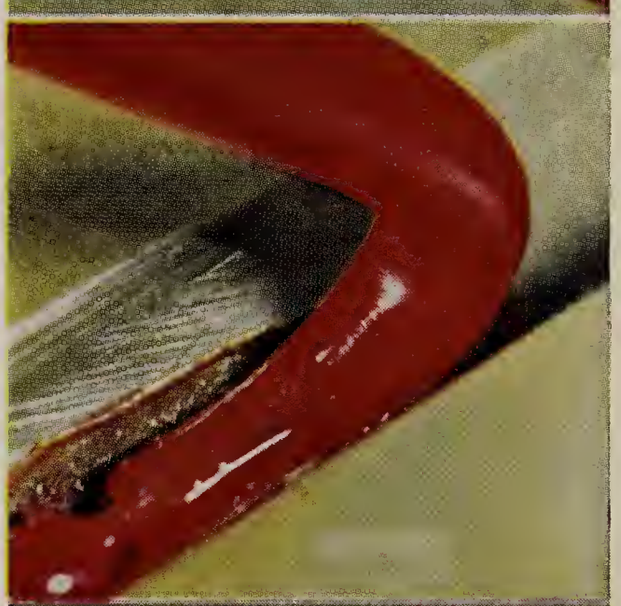
IX/4. The filler rod bends under the influence of heat (from the welding gas) and flows inside a prepared groove from left to right.

IX/5. Typical example of a good P.V.C. weld. Note the two waves (one on each side of the filler rod). The absence of these waves indicates insufficient heat, insufficient pressure or too great a speed.

IX/6. Note formation of softened material at the root. The softened (plasticised) material comes up on both sides of the filler rod in the form of waves (see 5).

IX/7. Insufficient pressure on the filler rod. The side waves are missing–unsatisfactory weld.

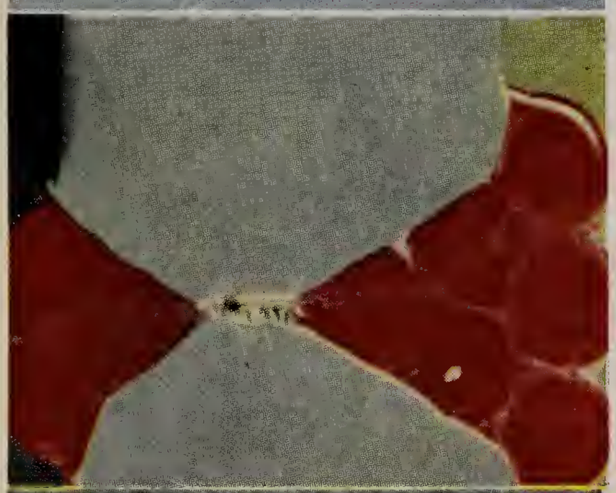
IX/8. Filler rod is stretched due to bending. Unsound weld. Note the crack in the filler rod.



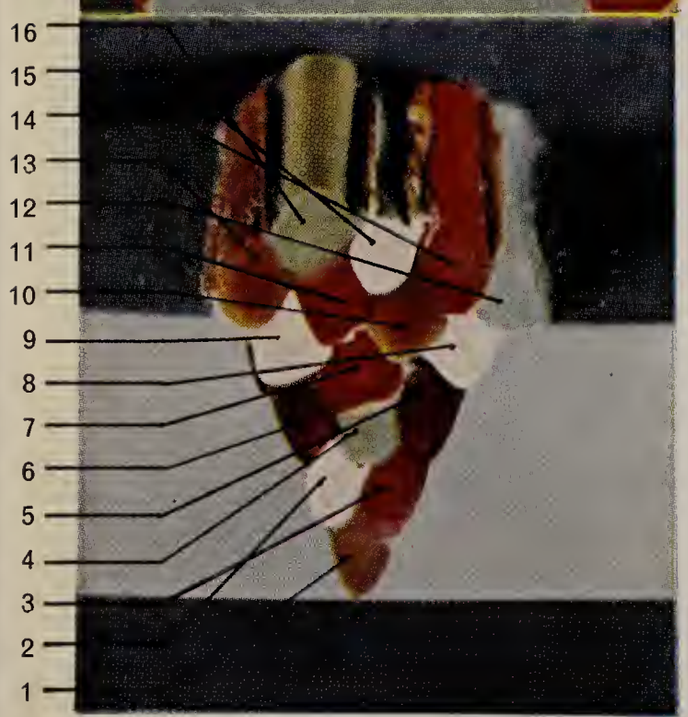
IX/9. Multi-layer weld–numerous fissures and cracks resulting from excessive stretching of the filler rod.

IX/10. Cross section through an unsatisfactory butt-weld. The individual layers are clearly visible. They are almost circular (little deformation or bonding).

IX/11. Cross section through a faulty butt-weld. The material is charred through an excess of heat.



IX/12. Cross section through a double butt-weld. Also unsatisfactory. Insufficient penetration at the root.

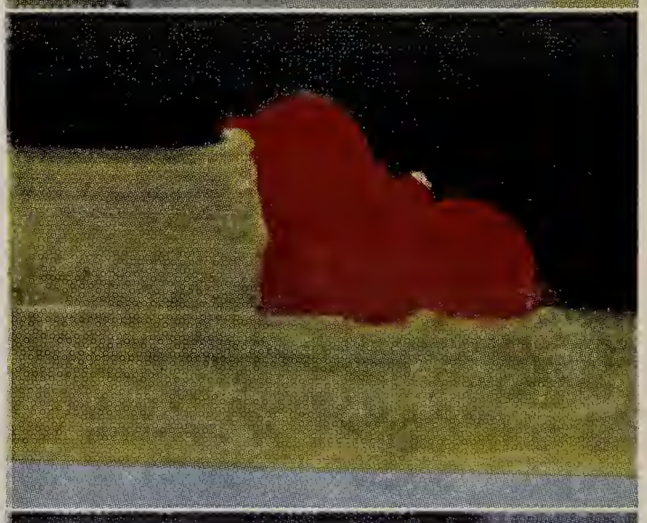


IX/13. Cross section through a multi-layer butt-weld (16 runs).

IX/14. A perfect butt-weld. Both the temperature of the welding gas and the pressure on the filler rod were set correctly. The individual layers have merged. Good penetration at the root.

IX/15. Another satisfactory weld (double butt-weld).

IX/16. Lap-welds have little mechanical strength.

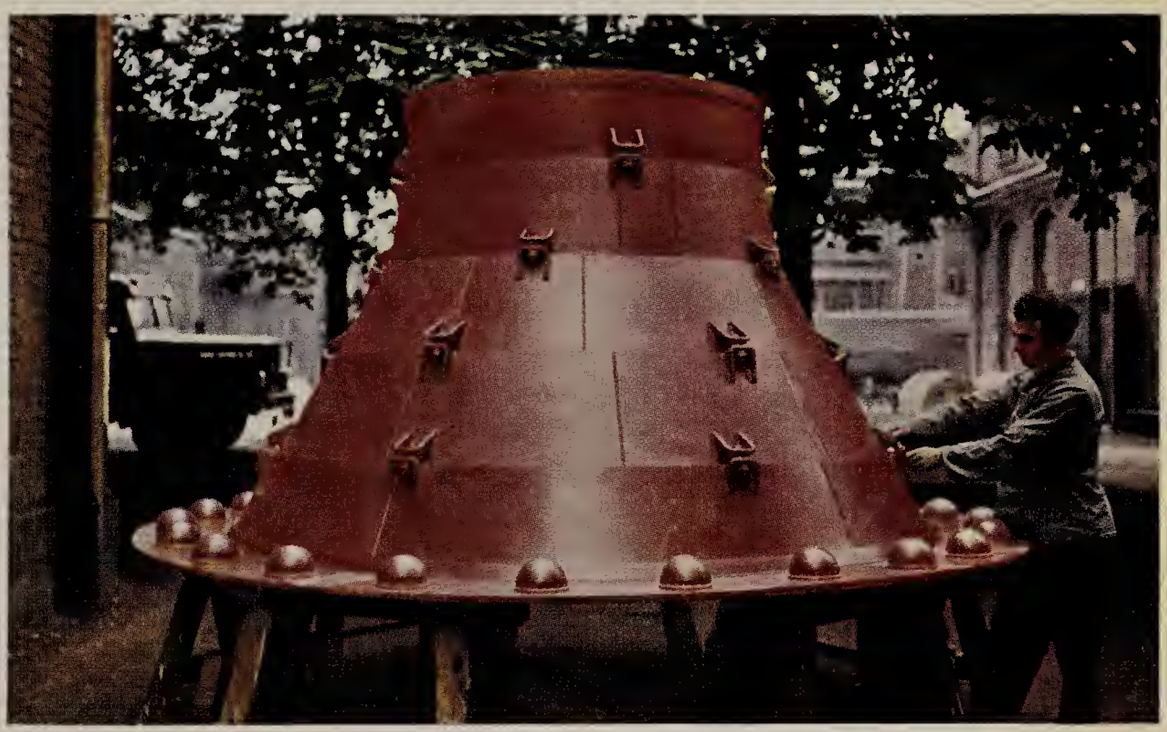


IX/17. Cross sections through various types of welds. **Top:** Corner weld–rather weak. **Centre:** Corner weld–reinforced on the inside. **Bottom:** Butt-welds are stronger than corner welds.

XVII/27.
P.V.C. Chimney (400ft high - 20 in. diam.) attached to Brick Chimney.

XVII/23.
Sodium Hypochlorite Filter Plant fabricated from rigid P.V.C. (Note: P.V.C. lined Steel Storage Tank underneath the filter plant).

XVII/24.
P.V.C. Weathering Cowl for Chimney.



XVII/25.
Aluminium Vessel (Condenser) fitted with P.V.C. cooling tubes.

pipes and fittings. Tentative standards for P.V.C. pipes and fittings were first issued in Germany in 1942, but it took many years before final standards were published (in 1958). Other countries were even more reluctant to approve plumbing in P.V.C., and proposals for standards for rigid P.V.C. pipes and fittings were only recently passed for comments to industry in Great Britain. The Americans and Canadians, too, have issued tentative standards, whilst some European countries are preparing standards of their own, not necessarily following German practice. Dutch standards for pipes and fittings are perhaps further advanced than all other standards of this kind; an international commission (I.S.O.) is meeting from time to time to prepare international standards which may, in time, be accepted by the whole of Europe.

It should be mentioned that the difference between these various standards are much wider than one would assume, even the practice of installing P.V.C. pipe lines varies from country to country. The Germans, for instance, frown upon the practice of using threaded pipes and fittings, perhaps with some justification, as the early types of P.V.C. were extremely prone to cracking due to the notches caused by pipe threads. The Americans and Canadians, on the other hand, use threaded pipes and threaded fittings to a large extent; this is the outcome of large-scale use of high impact P.V.C. which is not sensitive to notches.

So far, most firms specialising in P.V.C. plumbing have worked out their own methods which were, however, mainly based on German practice; this is quite understandable as most of the early literature on this subject was published by the Germans. As time goes on, and especially when official standards will become available, it can be expected that the procedure will be changed and that the methods and stipulations laid down in these standards will become general practice.

The methods and suggestions for the construction of rigid P.V.C. pipe lines given in this book are based on many years of practical experience in this country and abroad. They are not necessarily in line with British Standards at present under consideration, and it may be necessary to revise these methods when these Standards are issued.

Mechanical properties of P.V.C. pipes and pipe joints

Henning (*6*) carried out comprehensive tests to ascertain the strength of welded and cemented pipe joints in rigid P.V.C. (Vinidur) by subjecting specimens to tensile-, bending- and bursting-tests. All these were short term tests and do not therefore represent actual working conditions. The results (average of six tests) are quoted below as a ratio of the respective strength of the parent material.

Type of joint	*Tensile Test*	*Burst Test*	*Bend Test*	
Cemented sleeve	1·00	0·49	0·97	0·86
Cemented sleeve using a die for forming	0·88	0·39	0·82	0·99
Butt weld (not dressed)	0·77	1·00	0·97	0·97
Butt weld with sleeve (not cemented)	0·77	0·94	0·99	0·97
Butt weld with sleeve and additional weld at both ends ..	0·77	1·00	0·57	0·96
Butt weld with cemented sleeve	0·77	0·93	0·85	0·92

Variation in the skill of the operators, non-uniformity in the quality of the pipe, wall thickness, etc., have a far greater influence on the quality of the joint than the type of joint. Experiments show, however, that all types of joints when carried out properly can be used with a sufficient margin of safety.

Tensile Strength of Rigid P.V.C at various Temperatures

°F.	°C.	*Ordinary P.V.C* p.s.i.	*High Impact P.V.C.* p.s.i.
—40	—40	12500	11000
32	0	9000	7500
78	25	7000	6000
104	40	6000	4950
131	55	4700	3900
145	63	4200	3350
150	66	3900	3100
180	82	2700	1900

Izod Impact Strength at various Temperatures

°F.	°C.	*Ordinary P.V.C ft. lb./in. notch*	*High Impact P.V.C. ft. lb./in. notch*
—40	—40	0·3	1·0
32	0	0·4	4·0
78	25	0·9	10·0
145	63	4·0	18·0
180	82	16·0	19·0

Calculation of the maximum working pressure of rigid P.V.C. pipes

The safe working pressures for rigid P.V.C. pipes can be calculated using the Barlow formula. (*10*):

$$P = \frac{2T \times S}{D}$$

where P is the maximum (safe) working pressure in p.s.i.
T is the effective wall thickness in inches.
S is the allowable working tensile strength in p.s.i.
D is the outside diameter of the pipe.
(The wall thickness of threaded pipes has to be measured at the root.)

The Barlow formula is extensively used for working out the maximum working pressure of thin wall metal tubing, and for this purpose it is almost universally accepted. It has, however, some shortcomings as far as rigid P.V.C. tubing is concerned and more recently other formulae have been used by some European Pipe Committees, for instance, in Great Britain and also by I.S.O. (see page 165).

Exact long term data cannot be obtained without long term tests (for instance, details concerning the behaviour of pipes after 10,000 hours' use), but an approximation can be made by plotting on a log/log scale the bursting values vs. times for failures. As this graph is near enough a straight line—it is permissible to extrapolate the times for long term failure from experiments carried out over a comparatively short length of time.

Fluid flow through rigid P.V.C. pipe lines

The low coefficient of friction of rigid P.V.C. pipes often permits the use of smaller bore pipes than originally contemplated. The flow characteristics can be calculated from the formula:

$$P = \frac{0{\cdot}0605 \times 1{\cdot}45\ G}{4{\cdot}75D}$$

where P=the pressure loss in p.s.i. per 100 ft. of pipe.
G=the flow expressed in gal./min.
D=the inside diameter of the pipe in inches.

The increased flow rate is partly due to the low coefficient of friction on the smooth walls of the pipes; rigid P.V.C. resists the formation of scale which also contributes to the higher rate of flow.

Pressure losses in P.V.C. pipe lines are considerably lower than those in galvanized steel pipes of equal bore. The actual gain amounts, however, to not more than 15 per cent. as the pressure losses increase with the square of the velocity of the liquid passing through.

Fabrication Techniques (*3, 4, 5, 6, 7*)

Bending of pipes

Pipes up to $\frac{1}{2}$ in. bore can be bent without filling, and experienced plumbers may be successful in bending pipes up to 1 in. bore by simple preheating with an open flame. Fig. XIV/1. This often results in irregular temperature distribution and parts of the pipe may still be cold whilst others are already overheated or burnt. Internal stresses are created and sometimes overheating may lead to decomposition of the material. The flame should, therefore, not be brought into prolonged contact with the workpiece and should be moved backwards

Fig. XIV/1.—Preheating of a P.V.C. pipe with a torch before bending.

and forwards while the pipe is rotated. Overheating can be recognized by a darkening in colour or a slight formation of bubbles; overheated parts should be cut out as their chemical resistance and mechanical properties no longer correspond to those of the original material. Forming should follow the heating process quickly.

In the case of larger bore pipes, some kind of internal packing is required to avoid a reduction in cross-section and wrinkles. Plumbers springs are sometimes used for this purpose, but in general, filling with sand or inserting suitable rubber tubing is a safer method. Filling with sand is carried out in the same way as for metal pipes. The sand should be dry and of uniform grain size (approximately 40 mesh).

Tapping of the pipe walls with wooden or rubber mallets and further filling results in uniform filling of the pipe. Both ends of the pipe are then closed by stoppers. Preheating of the sand is desirable, otherwise

it has to be heated with the pipe which prolongs the preheating operation. Care should be taken that the outside of the heated pipe does not come into contact with sand as the individual grains will leave impressions on the pipe, thus not only spoiling its appearance, but also reducing its mechanical strength. When removing the sand the formation of dust should be avoided and it is recommended to carry out this operation in a special room or in the open.

Using rubber or Neoprene pressure tubing instead of sand, contamination by dirt and dust is avoided. Thick walled heat resisting Perbunan or Neoprene tubes approximately $\frac{1}{16}$ in. to $\frac{1}{8}$ in. smaller in o.d. than the i.d. of the pipe to be bent should be employed. Their length should be such that they extend at both ends of the pipe. High pressure tubing of smaller diameter is connected to both ends of the tube. The rubber or Neoprene tubing is inserted into the pipe before preheating and is inflated once the bending temperature is reached; the tubing will fill the inside of the P.V.C. pipe completely. Bending should then commence at once. After cooling, the rubber tubing is deflated and withdrawn by means of a hook.

Bending of pipes on a larger scale can be simplified by using the pipe bending machine shown in Fig. XIV/2. The pipe to be bent is placed on the machine, pressure tubing of suitable size is inserted and blown up with compressed air so that it fills the tube completely. Air from a fan is then blown over some heater elements and this hot air is used to soften and plasticize the pipe. Once the correct degree of plasticity is reached the pipe is pushed against two limiting bars which have previously been set under the correct angle. The tube is then held by one operator whilst his helper wipes the bent pipe with a wet sponge or a wet cloth to effect consolidation. This type of machine allows bending of pipes up to 4 in. bore but in exceptional cases, with experienced operators, pipes up to 6 in. can be bent. This type of machine is in use in several large workshops in Germany but it is only really justified for mass production.

Another way of effecting preheating before bending is by inserting the pipes into an oven with forced air circulation with the end of the pipes sticking out on each side. This method is particularly suitable for making large cooling coils. The pipe which has been preheated over its entire length has, of course, to be filled with sand to prevent collapsing. It can be taken from the oven and rolled over a suitable former without much difficulty,

A novel and very simple method of bending pipes is by applying heat from infra-red heater rings which are available in various diameters. The pipe to be bent is pushed through the heater ring which is then moved slowly over the area to be preheated. Once the material becomes soft and pliable the bending operation can be performed but it is still necessary to fill the pipe with sand or pressure tubing or springs to

prevent partial collapse, or kinking, during the bending operation.

There are obvious limitations to the bending of rigid P.V.C. pipes; bending the pipes over too short a radius will cause cracks and splitting of the pipes. The following radii should not be exceeded:

Bore	*Smallest Radius*
$\frac{1}{4}$ in.—1 in.	At least 2 × outside diameter of the pipe
1 in.—3 in.	,, ,, 3 × ,, ,, ,, ,,
3 in.—6 in.	,, ,, 4 × ,, ,, ,, ,,

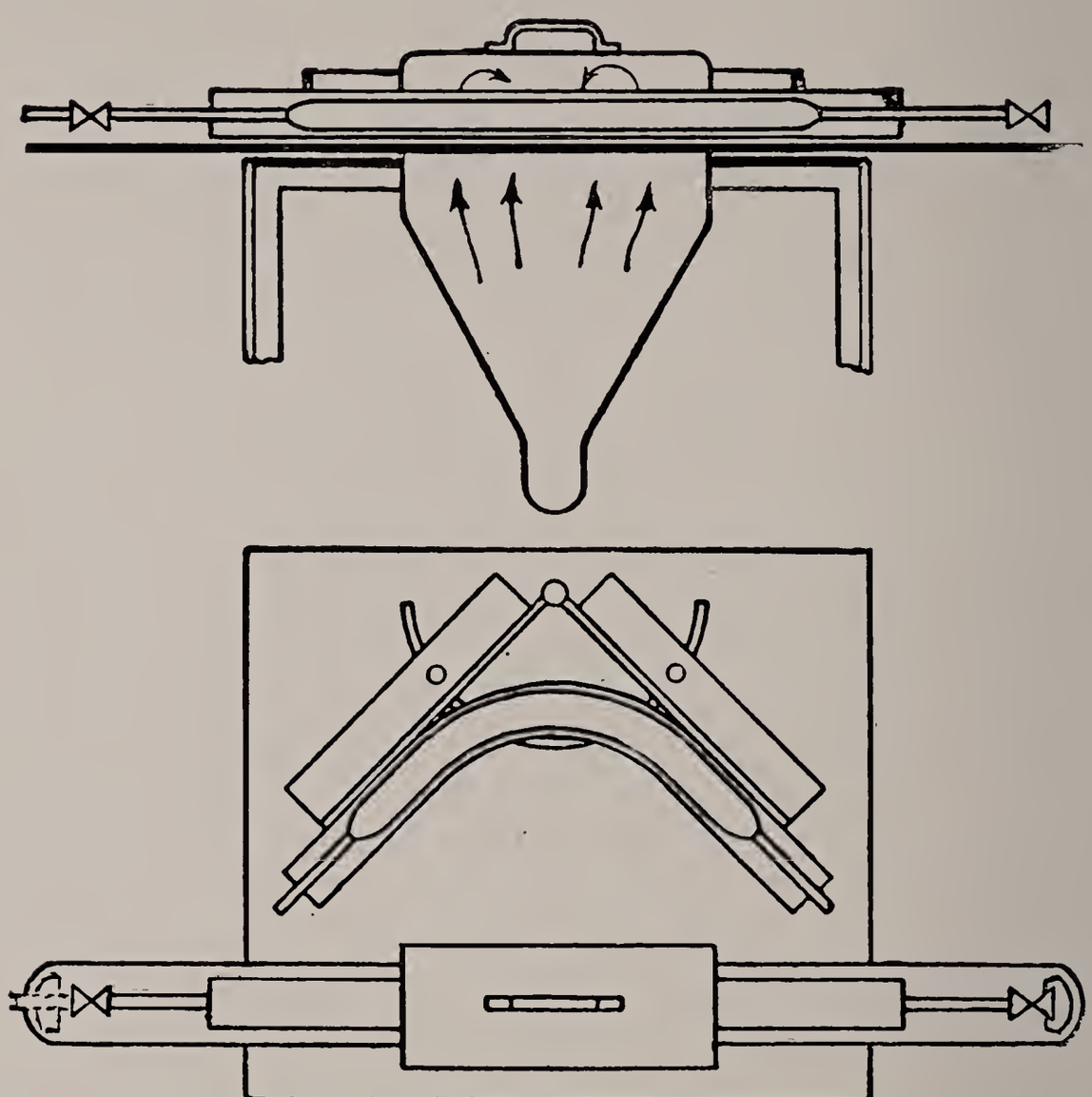


FIG. XIV/2.—P.V.C. Pipe bending machine.

Pipes of heavier wall require a greater angle of bend than thin wall tubing. Pipes larger than 6 in. in bore cannot be bent by heat-forming and bends have to be fabricated by welding (lobster back).

Cemented joints

Cementing of rigid P.V.C. pipes is recommended only for lap joints—butt joints are impracticable. The technique used for making joints of the bell and spigot types is shown in Fig. XIV/3.

The pipe end to be inserted is bevelled at an angle of 20° and subsequently rounded off. The pipe to be expanded (belled) is then heated over a length of approximately 1·5 times that of the bore of the pipe to a temperature of 265° to 270° F. (125° to 132° C.) by heating with a soft flame from a bunsen burner or blow lamp; alternatively the pipe end to be belled can be immersed in an oil or glycerine bath kept at the temperature mentioned above. Care should be taken to heat the pipe uniformly and to prevent burning.

Table V contains recommendations for the depth of belling for various pipe sizes.

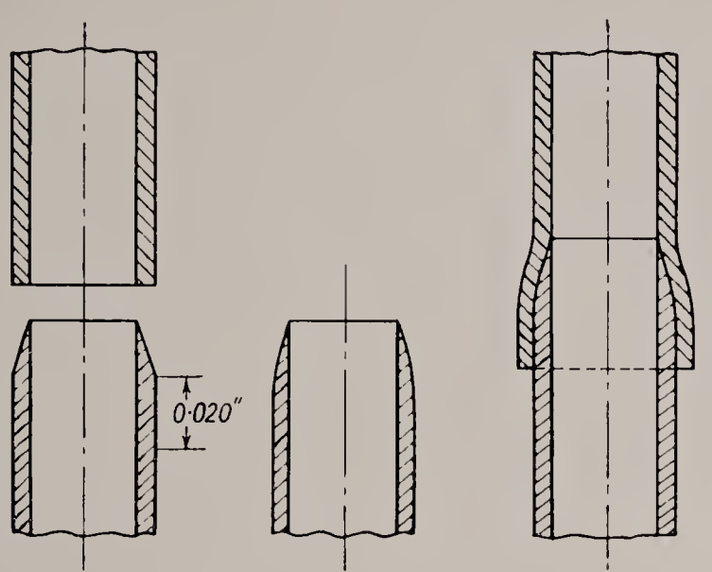


Fig. XIV/3.—Making a bell and spigot joint (cemented).

Table V

Nominal Bore:	$\frac{1}{4}$ in., $\frac{1}{2}$ in., $\frac{3}{4}$ in., 1 in., 2 in., 3 in., 4 in., 5 in.
Depth of Bell:	$\frac{3}{4}$ in., 1 in., $1\frac{1}{2}$ in., $1\frac{3}{4}$ in., 3 in., 4 in., $4\frac{1}{4}$ in., $5\frac{1}{2}$ in.

The softened pipe end is then pushed over an appropriate former (plug gauge), the diameter of which should be approximately $\frac{1}{16}$ in. smaller than the outside diameter of the pipe to be inserted and subsequently cooled by immersion in water with the plug gauge previously removed. The belled end is then dried and decreased on the inner surface by wiping with methylene chloride and roughened with sandpaper. The pipe end to be inserted is now roughened in the same way and painted carefully with a suitable cement, care being taken to prevent an excess of cement; it is then firmly pushed into the belled part of the other pipe and left for at least 12 hours to consolidate, if possible under pressure.

Overwelding on the circumference is usually not required, but in cases where this is done all traces of the cement have first to be removed. Where speed is essential, forced drying of the cemented joint with warm air not exceeding 105° F. (40° C.) is permissible. At low temperatures (in winter) forced drying may be necessary as the cement will set very

slowly. Good fitting is essential as the cement has a very low solids content and cannot fill gaps or voids; on the other hand an excess of cement in a cavity will cause penetration of the solvent into the pipe which it will weaken in due course.

Cemented sleeves are sometimes used for repair work (over butt-welds or single-layer repair welds); the strength of such a joint is, however, not sufficient to warrant their application for pipe work in general.

Welded joints

Welded joints in rigid P.V.C. pipe work are practicable only where the wall thickness is at least $\frac{3}{16}$ in. or heavier. Butt-welds should be used wherever possible and care should be taken to avoid stresses in the weld.

Butt-welds (see Fig. XIV/4).

Pipe ends requiring welding are bevelled at an angle of 30°, so that an included angle of 60° is formed. A root gap of 0·020 in. to 0·040 in. should be provided to yield good penetration. Filler rods used should be $\frac{1}{8}$ in. thick except for the first run which is usually deposited with $\frac{3}{32}$ in. rods. Care should be taken during the deposition of the first run—as welding can only be carried out from one side. This first layer should penetrate approximately 0·040 in. into the interior of the pipe; such penetration can be achieved by slight pressure on the welding rod. Care should be taken that each run is welded properly to the preceding layer, avoiding voids at all costs. Notches in the transition zone between weld and pipe are dangerous and should be carefully avoided. Dressing of the finished weld is not recommended as it reduces the tensile strength.

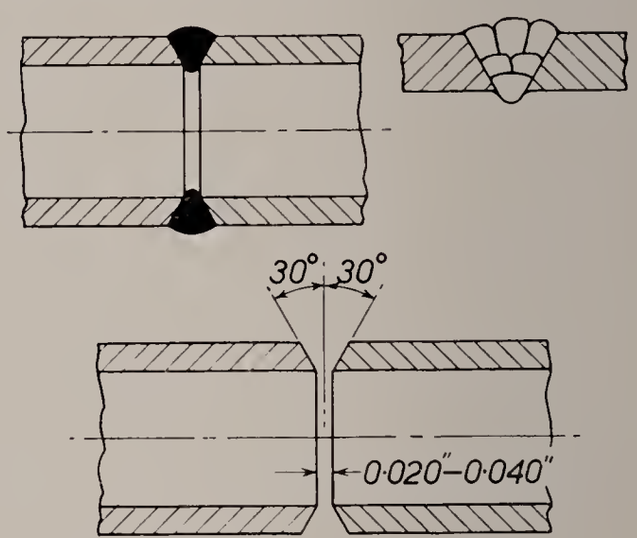


Fig. XIV/4.—Butt-weld on a P.V.C. pipe.

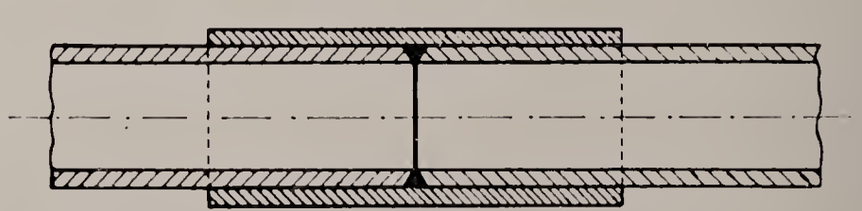


Fig. XIV/5.—Butt-weld with shrunk-on sleeve.

Butt-welds with shrunk-on sleeves. The addition of a shrunk sleeve protects the weld with regard to excessive bending stresses and increases

the resistance to fatigue (see Fig. XIV/5). The fact that the crown of the weld has to be dressed is not a serious disadvantage in this particular case. The sleeve can be made from the same type of pipe or, in the case of pipes of very heavy wall, from pipes with thinner walls.

After cutting to size, the sleeve is preheated to approximately 270° F. (130° C.) and pushed on to a greased mandrel the diameter of which is $\frac{3}{32}$ in. larger than the o.d. of the pipe to be sleeved.

Following this operation the sleeve is quenched in water and withdrawn from the mandrel. The weld is made in the same way as a butt-weld. Following the welding operation any excess of weld material is dressed; the sleeve is then pushed over the welded joint so that the centre of the sleeve coincides with the welded seam. Subsequently, the sleeve is heated by means of hot air or a soft flame to shrink it on to the pipes. In addition, the sleeve can be cemented on; tack welding at both ends of the sleeve is sometimes carried out—for instance, during repair work—where there are doubts about the quality of the butt-weld underneath.

Doubles sleeves with pipe insert. Whenever positional welding has to be carried out, i.e. when the pipe cannot be rotated and it is, therefore, impossible to align both pipe ends properly or where it is impossible to provide the necessary gap of 0·020 in.–0·040 in., a double sleeve with a pipe insert should be used (see Fig. XIV/6). In such cases the inner edges of both pipes should be carefully welded to the pipe insert and the gap between them should be filled with weld deposit. Bevelling of the inserted pipe piece and expansion of the pipe ends are performed in the same way as for overlapping sleeves.

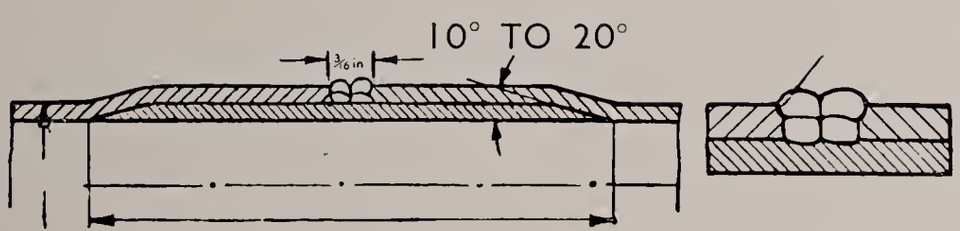


FIG. XIV/6.—Double spigot joint with pipe insert.

Comparison between welded and cemented joints

Cemented joints resist bending and deformation better than welded joints whilst the latter have a greater bursting strength.

Both types of joints have their peculiarities and their use is governed by the service condition of the pipeline. Plumbers in plastic materials should be able to perform both types of jointing and they should be familiar with their advantages and shortcomings. In factories with fire risks and explosion hazards, welding is usually out of the question. Cemented joints cannot be stressed for the first 24 hours

of their life and in cases where speed is essential, preference may be given to welding.

P.V.C. pipes are occasionally stressed up to the endurance limit or may have to be used just at the safe limit for continuous operation. Cemented joints are not always perfectly inert against chemical attack. In all such cases only welded pipe joints are permissible.

Fittings

Plumbing in rigid P.V.C. is greatly facilitated by the use of moulded fittings. These are now available in a wide variety comprising elbows

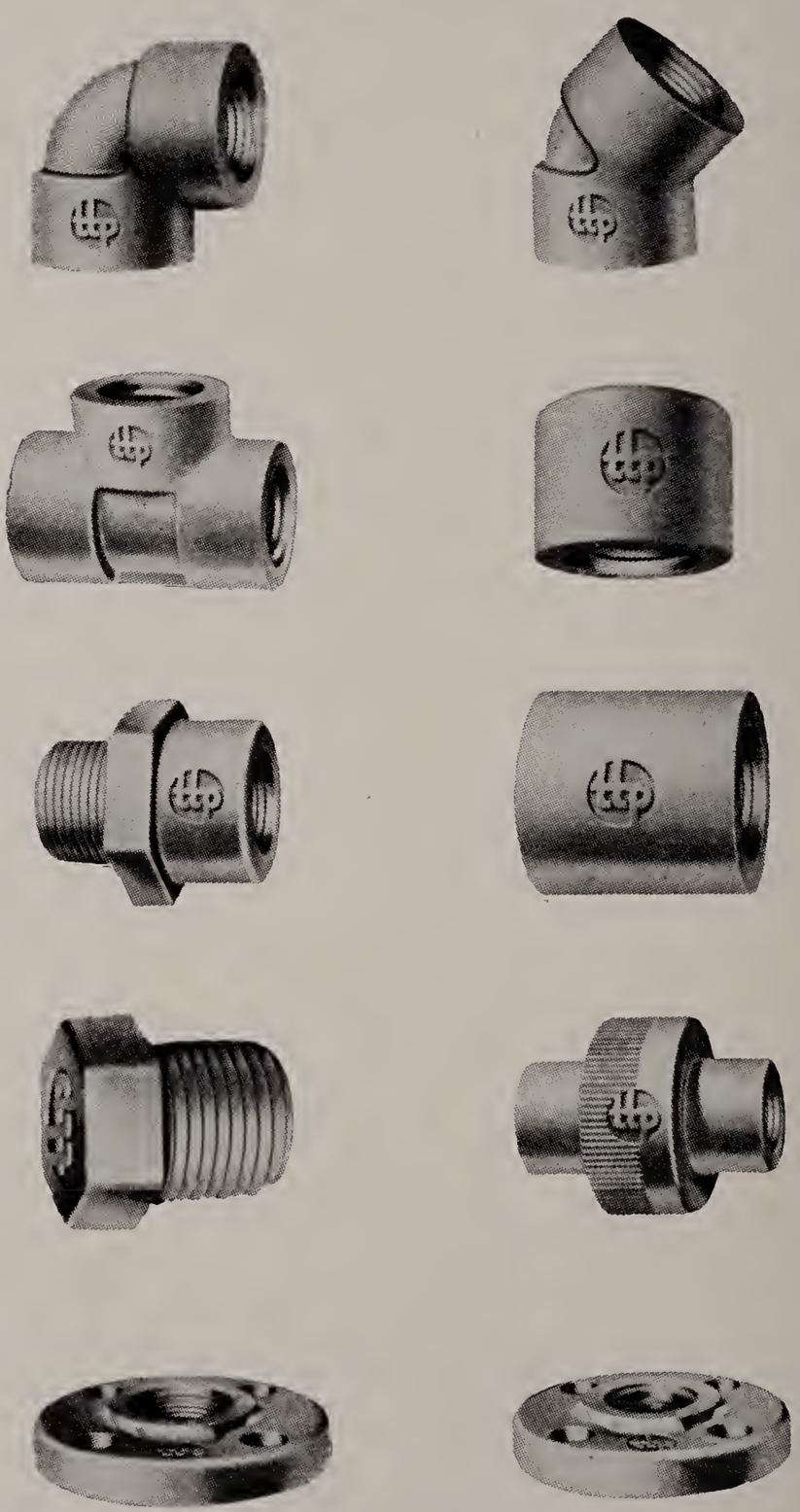


FIG. XIV/7.—Moulded P.V.C. fittings.

(45° and 90°), T-pieces (45° and 90°), caps, sockets, reducing sockets, couplings, plugs, unions and flanges. They are either threads (mainly for high impact type P.V.C. pipes) or socketed for cementing (solvent welding) or gas welding. American pipe manufacturers offer all these fittings in sizes from $\frac{1}{2}$ in. to 12 in. bore. (Fig. XIV/7). British firms offer at present a limited range of elbows, tees, reducing pieces and flanges mainly up to 4 in. nominal. Continental firms provide moulded P.V.C. fittings for pipes up to 2 in. bore.

Rigid P.V.C. 'Instrumentation' fittings produced by an American firm provide a successful and simple means of connecting polythene and plasticized P.V.C. tubing for instruments (manometers, pressure gauges, etc.). They fit tubing of $\frac{1}{4}$ in. and $\frac{3}{8}$ in. bore and can be employed for systems with a maximum pressure of 100 p.s.i. at 75° F. (27° C.).

Fabrication of P.V.C. pipe lines using moulded fittings

Moulded P.V.C. fittings are either of the socketed or the threaded type. Methods of assembly vary according to the type of fitting used.

Socketed fittings

The use of socketed fittings makes cementing necessary. The pipes are usually slightly larger in diameter than the bore of the sockets of the fittings and have to be adjusted. The pipe ends are cut square and slightly chamfered. The end to be fitted is then heated with a blow lamp or a bunsen burner until it becomes soft and plastic; it is then pushed into a sleeve gauge (up to the marking in the gauge) and cooled in water to ambient temperature. The sleeve gauge should not be withdrawn until the pipe end has reached room temperature. The calibrated end should now fit the socket with hardly any clearance.

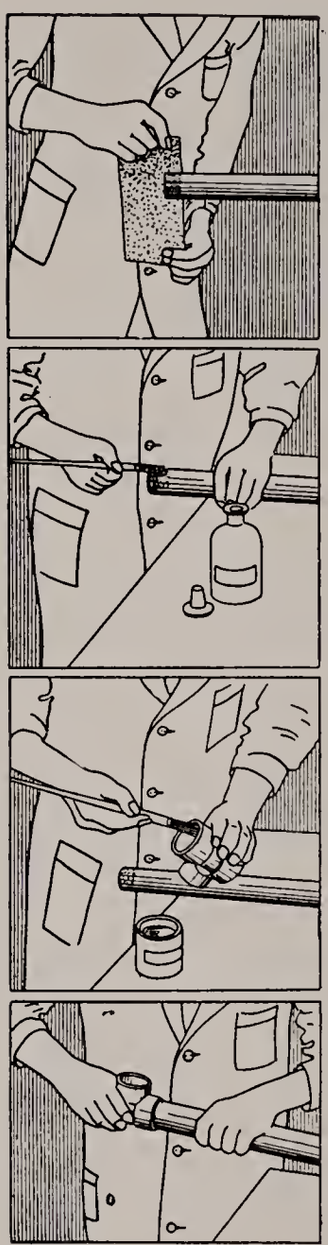
If the pipe end is too small in diameter, i.e. if there is too much clearance between pipe and socket, the former should be reheated so that it expands, it is then again pushed into the gauge and cooled down.

Further operations involve roughing of the pipe end with emery paper, degreasing of the area to be inserted with methylene chloride, applying of a suitable cement by means of a brush and finally fitting into the socket of the fitting. At least 12 hours should elapse before it can be put under pressure. Details of cementing are shown in Fig. XIV/8.

Threaded fittings

Threaded fittings require threaded pipe ends. Threading is recommended for high impact type P.V.C. pipes only—the low impact strength of ordinary type P.V.C. pipes is further reduced by notching and makes this method of jointing rather hazardous. It should, however, be mentioned that ordinary rigid P.V.C. pipes are also threaded in U.S.A. provided the pipes are of sufficient wall thickness: schedule 80 and over.

Threading can be carried out by hand tools or on a pipe-threading machine. Die chasers should have a 33° chamfer on the lead and a negative rake up to 10° on the back or a relief edge. It is of advantage to use a tapered plug which should be tapped into the end to be threaded in order to prevent the die from digging into the wall of the pipe and distorting it. The pipe end held in the vice should be protected with a piece of canvas, a rag or a light metal sleeve to avoid scratching.



(1) Roughing with emery-paper and cleaning.

(2) Degreasing by painting with methylene-chloride

(3) Brushing-on the cement.

(3) Pushing the tube into the fitting.

FIG. XIV/8.—Cementing a P.V.C. pipe into a socketed fitting.

Thread compounds should be used when assembling a pipe line having threaded connections; those based on Teflon or Fluon are specially recommended for this purpose as they are completely inert to all chemicals which may pass through a P.V.C. pipe line. They retain their lubricating quality indefinitely and do not age or bind.

P.V.C. pipe lines assembled by means of threaded fittings can be put under pressure without delay; this saving in time is important.

The following example is quoted to illustrate the speed with which P.V.C. pipe lines can be assembled.

National Tube, an American Company manufacturing rigid P.V.C. pipes, demonstrated the laying of a 2 in. pipe line 2,800 feet long in the Permian Basin oil field. A pipe-laying crew with no previous experience assembled this line, consisting of 90 individual sections, in one hour and forty-five minutes; this represents a rate of approx. one joint per minute. The technique used was cementing—the fittings were of the socket type.

Detachable joints

Detachable joints allow for the manufacture of P.V.C. pipe lines in a workshop and greatly facilitate assembly on site. A certain number of detachable joints is always required so that the pipe line can be dismantled for cleaning and inspection. Screwed joints are more frequently used in the U.S.A. and Canada on account of high costs for labour (and lack of skilled operators). European countries have, until quite recently preferred fixed flange joints or fully welded pipe lines.

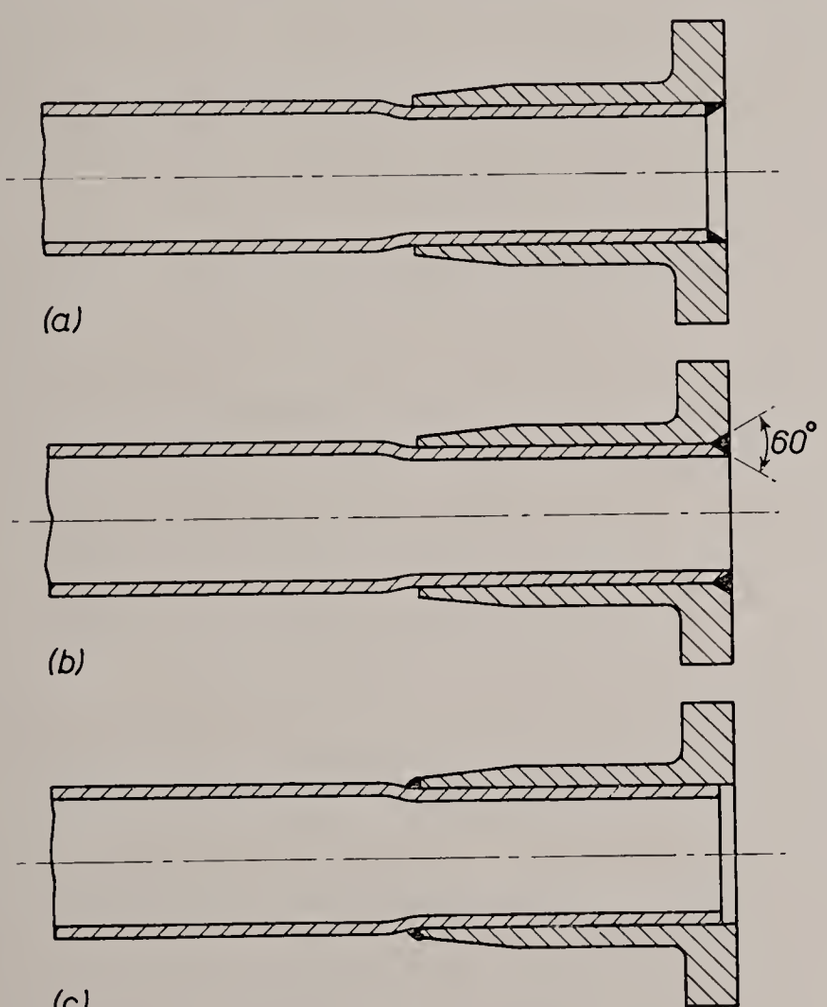


FIG. XIV/9.—Methods of attaching P.V.C. sockets (stub-ends) to P.V.C. pipes.

Stub-ends

Moulded P.V.C. stub-ends are often used for making detachable connections. The inner bore of these stub-ends should be slightly smaller than the outside diameter of the pipes over which they are to

be fitted. The pipe ends are carefully softened by heating to 270° F. (130° C.) and are then pushed into the stub-ends so that a very tight fit is produced. Stub-end and pipe-end are cemented together after cooling. (See Fig. XIV/9.) Subsequent welding as shown in Fig. XIV/9c is not permissible. Figs. XIV/9b and XIV/9a show the correct way for attaching stub-ends.

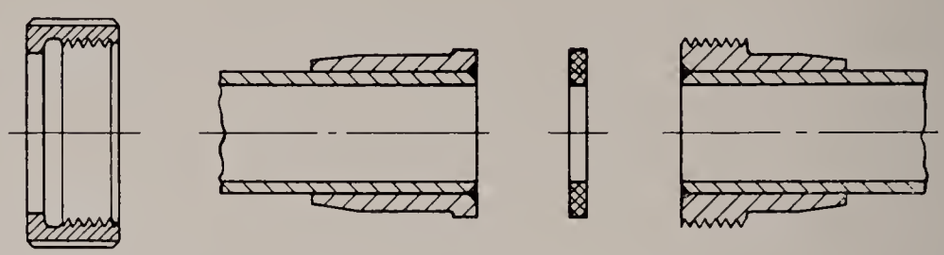


FIG. XIV/10.—Screwed unions with P.V.C. stub-ends.

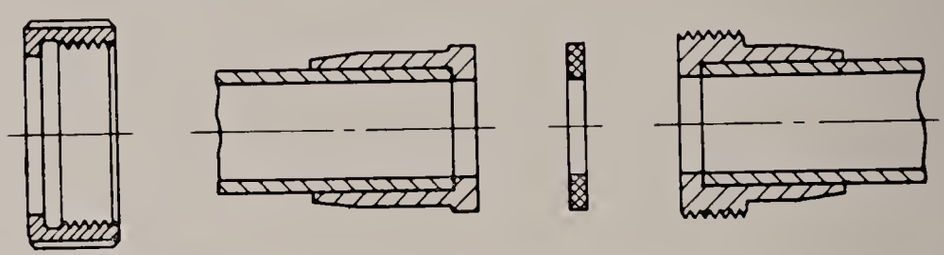


FIG. XIV/11.—Alternative method for screwed unions with P.V.C. stub-ends.

Figs. XIV/10 and XIV/11 illustrate alternative methods for screwed unions made with stub-ends, Fig. XIV/12 a detachable joint with stub-ends and loose flanges.

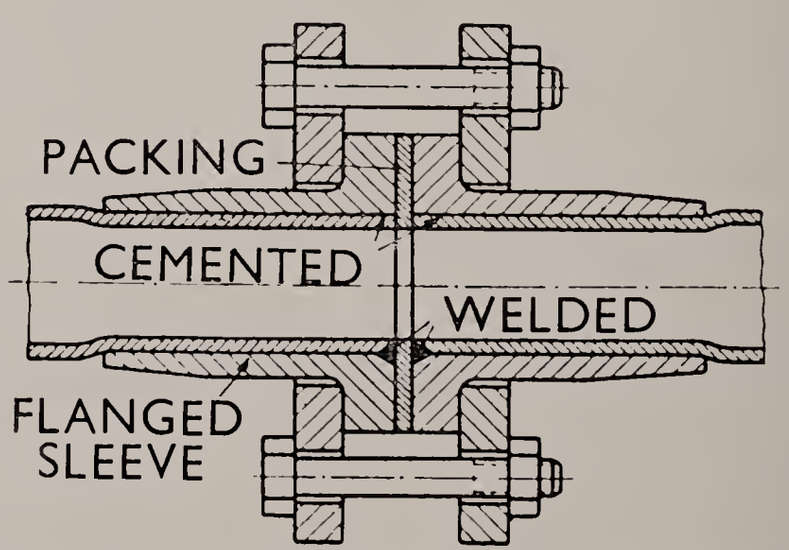


FIG. XIV/12.—Flanged sleeve joint with backing flanges.

A detachable P.V.C./Steel pipe connection using a steel union shown in Fig. XIV/13.

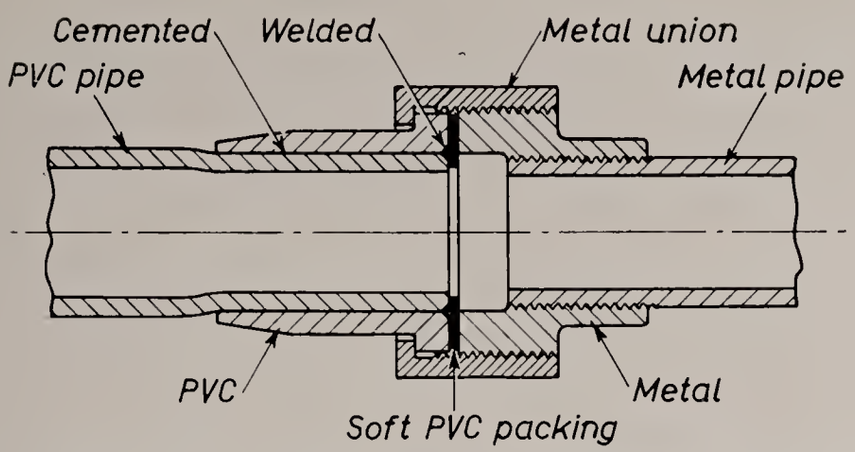


FIG. XIV/13.—Connecting a P.V.C. pipe to a metal pipe using screwed unions.

Flanged joints

Flanged joints are widely used in preference to other joints. Full-face flanges (see Fig. XIV/14) are rather expensive, and therefore, less frequently used than P.V.C. rings with loose backing flanges (Fig. XIV/15) which can be turned from metal, wood, laminated phenolics, or rigid P.V.C. Full-face flanges have to be welded to the pipe and must, therefore, be fabricated from rigid P.V.C.

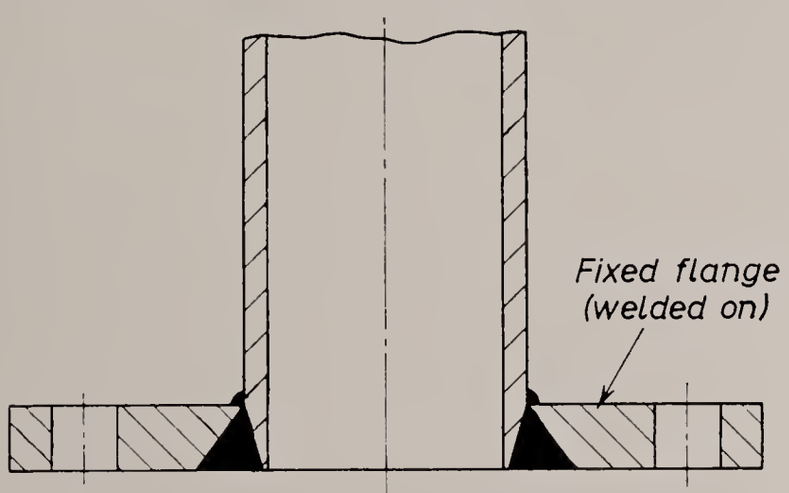


FIG. XIV/14.—P.V.C. pipe with welded flanges.

An alternative method for making joints with loose flanges using cemented-on sockets or sockets attached by friction welding is given in Fig. XIV/16.

In order to obtain the maximum weld-strength the highest degree of penetration should be aimed at. Weld reinforcements should be provided at the face of the pipe, but these have to be dressed subsequently. Welding on the other side has to be performed very carefully, leaving a good radius between flange and pipe. Any abrupt change of contour or notches may cause fracture.

Expansion

The high coefficient of expansion of rigid P.V.C. (8×10^{-5} in./in./°C.) becomes a problem of major importance in the case of longer pipe

lines. A rise in temperature, for instance, from 10° C. to 60° C. causes an increase in length of 0·4 per cent.; a fall in temperature of 50° C. causes a reduction in length of similar magnitude. Proper compensation for these dimensional changes has to be provided otherwise stresses of considerable magnitude would occur, causing fracture of the pipes.

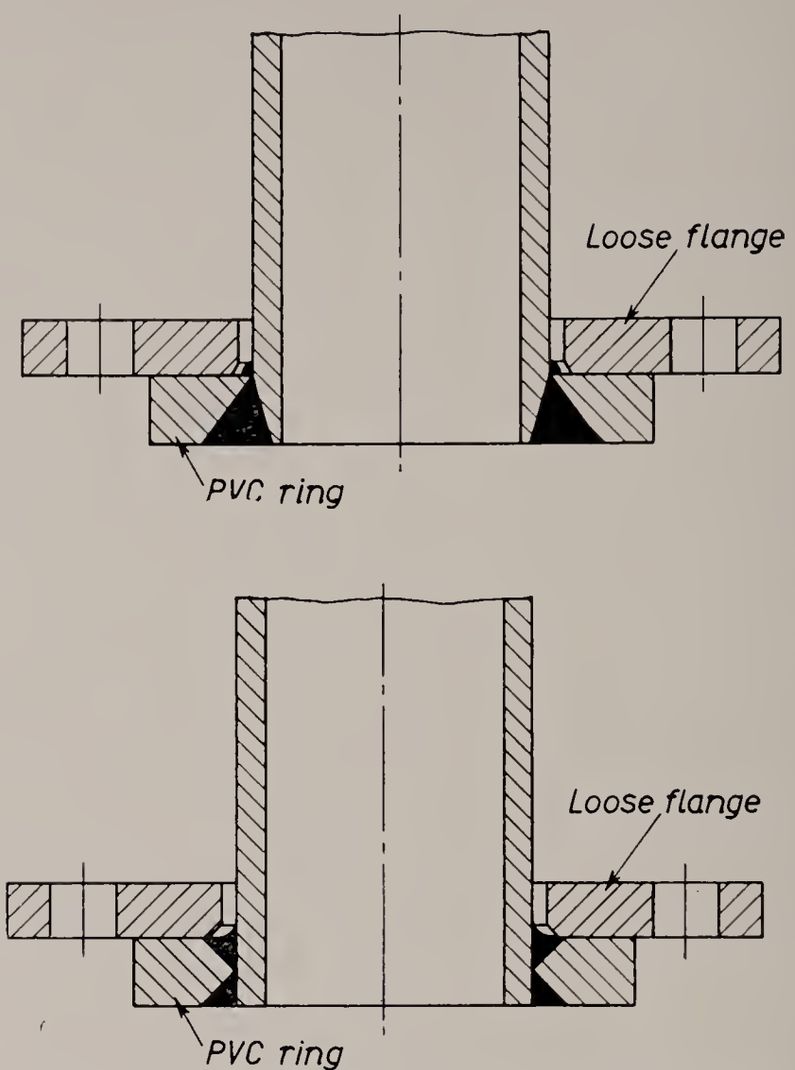


Fig. XIV/15.—P.V.C. pipes with loose flanges.

A satisfactory method of compensating for expansion, without installing designed expansions pieces, is to arrange the pipe route to include bends so that the intermediate lengths between the anchor points act as flexible units in which stresses at all points are below the maximum allowable. Full stress calculations are necessary to ascertain the safe limits where longer and larger bore pipe lines are involved and designed expansion pieces have to be installed when the pipe lines are destined to work at elevated temperatures.

The simplest way of compensating is by using external sleeves with joint rings and backing flanges; their use is, however, restricted to applications where gases or fumes and liquids, free from solid matter, are involved.

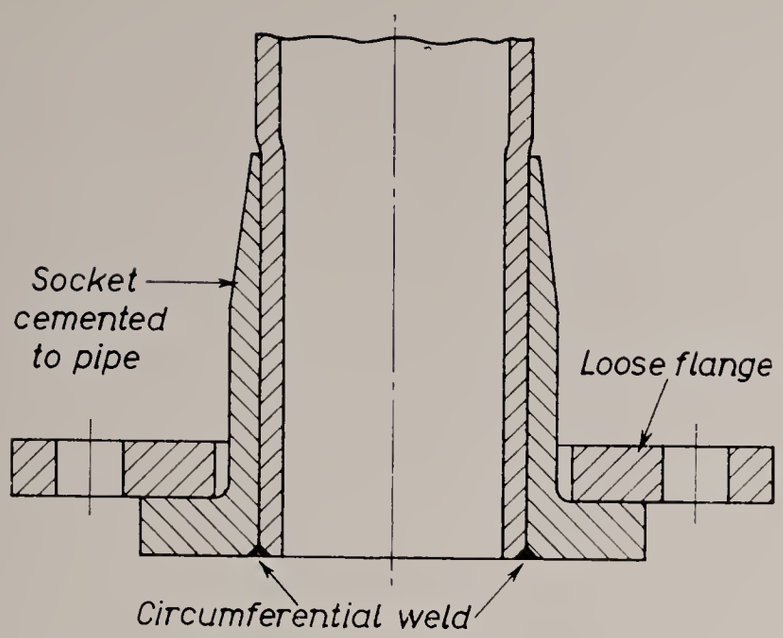


FIG. XIV/16.—P.V.C. stub-end with loose flange on P.V.C. pipe.

Lyre expansion pieces (see Fig. XIV/17) are usually made in one piece; the apex of the expansion piece is often supported as it is a fixed point from which the pipe line moves in both directions. It is quite permissible to build a lyre expansion piece in such a way that it consists of two identical halves with attached flanges joined at the apex.

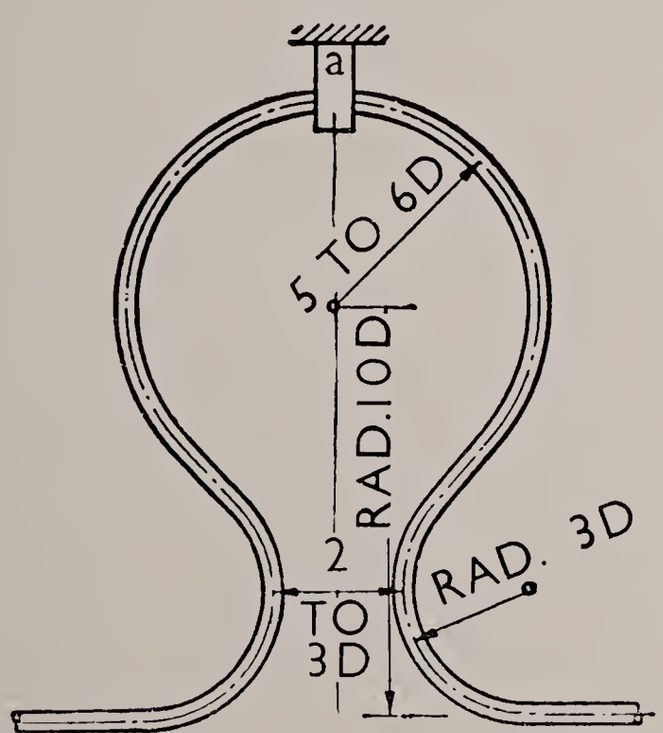


FIG. XIV/17.—Expansion piece: Lyre type.

Square type expansion pieces, see Fig. XIV/18, are easier to fabricate and they are, therefore, often preferred to the lyre type expansion piece. They can be made in sections with sockets or flanges in the centre.

Square expansion pieces can be subjected to the maximum pressure allowable for this type of pipe.

Morgan (*9*) has calculated the figures for cold pull-up, the total permissible travel, the permissible deformation from free position and the maximum permissible distance between bend centres for lyre type

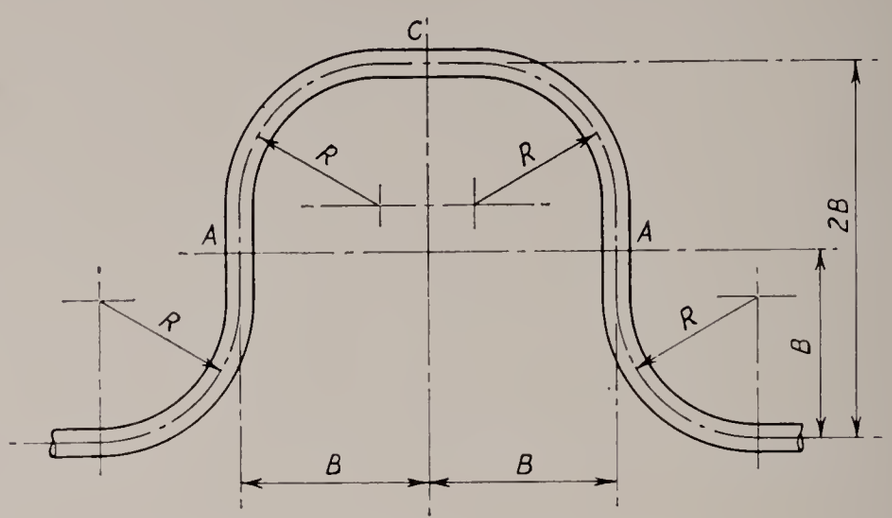


FIG. XIV/18.—Expansion piece: Square type.

and square type expansion pieces. These figures are reproduced in Tables VI and VII; they apply, of course, only to the specific sizes quoted and would have to be amended for other sizes or different wall thicknesses.

TABLE VI

DESIGN DETAILS FOR LYRE TYPE EXPANSION PIECES

Nom. Bore in in.	*Int. Dia. mm.*	*Out. Dia. mm.*	*Service up to 40° C.*				*Service up to 60° C.*			
			C. P.U. in.	*P. Def. in.*	*T.T. in.*	*M. P.D. ft.*	*C. P.U. in.*	*P. Def. in.*	*T.T. in.*	*M. P.D. ft.*
$\frac{3}{4}$	19	25	0·91	0·22	1·13	23	0·91	0·11	1·02	18
1	26	32	1·30	0·38	1·68	44	1·30	0·20	1·50	26
$1\frac{1}{2}$	36	40	2·93	0·98	3·91	102	2·93	0·52	3·45	60
2	52	60	3·31	0·85	4·16	109	3·31	0·44	3·75	65

C.P.U. = Cold pull-up in inches.
P.Def. = Permissible deformation from free position in inches.
T.T. = Total permissible travel in inches (C.P.U. + P.Def.).
M.P.D. = Max. permissible distance between bend centres in feet.

TABLE VII

DESIGN DETAILS FOR SQUARE TYPE EXPANSION PIECES

Nom. Bore in in.	*Int. Dia. mm.*	*Out. Dia. mm.*	*R*	*B*	*Service up to 40° C.*				*Service up to 60° C.*			
			in.	*in.*	*C. P.U. in.*	*P. Def. in.*	*T.T. in.*	*M. P.D. ft.*	*C. P.U. in.*	*P. Def. in.*	*T.T. in.*	*M. P.D. ft.*
$\frac{3}{4}$	19	25	$3\frac{3}{8}$	$5\frac{7}{8}$	1·18	0·28	1·46	38	1·18	0·14	1·32	23
1	26	32	$4\frac{1}{2}$	$7\frac{1}{2}$	1·65	0·48	2·13	55	1·65	0·25	1·90	33
$1\frac{1}{2}$	36	40	$6\frac{3}{4}$	$9\frac{3}{4}$	2·82	0·94	3·76	98	2·82	0·50	3·32	58
2	52	60	9	$12\frac{1}{2}$	2·85	0·73	3·58	93	2·85	0·37	3·22	56
3	79	90	$13\frac{1}{2}$	$17\frac{1}{2}$	4·09	1·01	5·10	133	4·09	0·52	4·61	80
4	103	110	18	23	6·35	1·98	8·33	217	4·95	0·81	5·76	100
6	150	160	36	43	6·74	2·12	8·86	230	4·95	0·81	5·76	100

Cheaper alternatives are bell and spigot fittings (sliding fit) with inserted P.V.C. hose, see Fig. XIV/20, and fabricated compensators made from pipe off-cuts (see Fig. XIV/19). The former are suitable for pipes not exceeding 2 in. in bore, the latter for very much larger pipes and even for ducting (low pressures only).

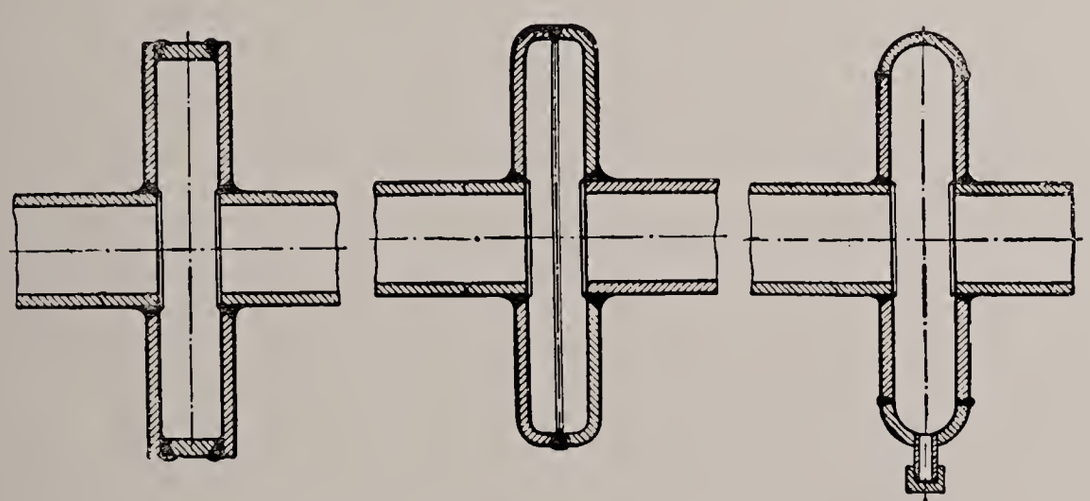


FIG. XIV/19.—Expansion pieces fabricated from off-cuts.

Bellows fabricated from Fluon, Teflon, plasticized P.V.C. or Neoprene, are suitable alternatives to expansion pieces. They are mainly used for pipes of larger diameter (4 in. and over).

Friction between P.V.C. pipes resting on stationary support hinders axial expansion. It may, therefore, be necessary to place the supporting brackets on rollers similar to the practice for steel pipes.

Supports

Rigid P.V.C. pipe lines require a fair amount of support. They can be fixed to walls and to ceilings by means of clips and saddles made from metal or from P.V.C. off-cuts. Overhead lines can be suspended

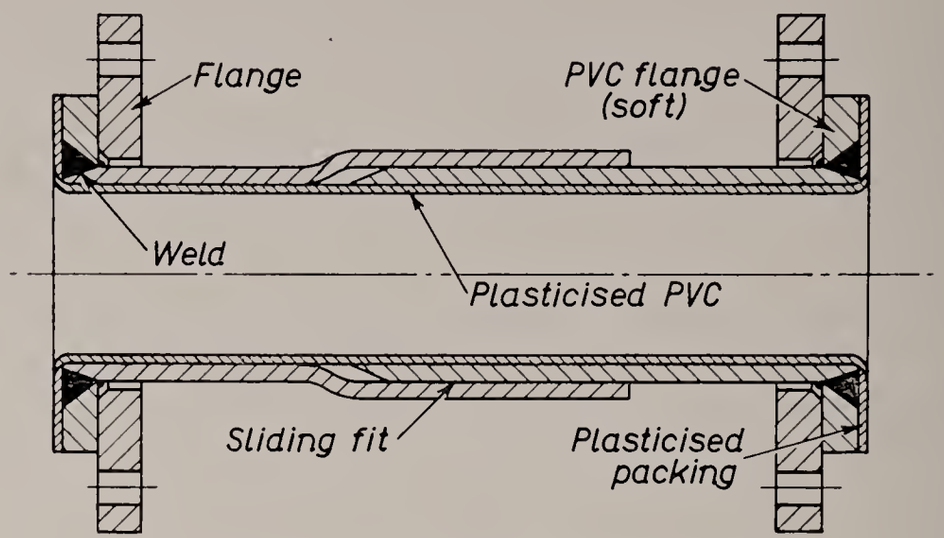


FIG. XIV/20.—Alternative expansion joint.

from the ceilings with stirrup hangers or pipe saddles. They should be lined with a soft material (rubber, plasticized P.V.C., felt, etc.) to prevent damage to the external surface of the pipe and they should be fitted loosely to allow movement of the pipes in the direction of their axis when subject to expansion or contraction. Figs. XIV/21 and

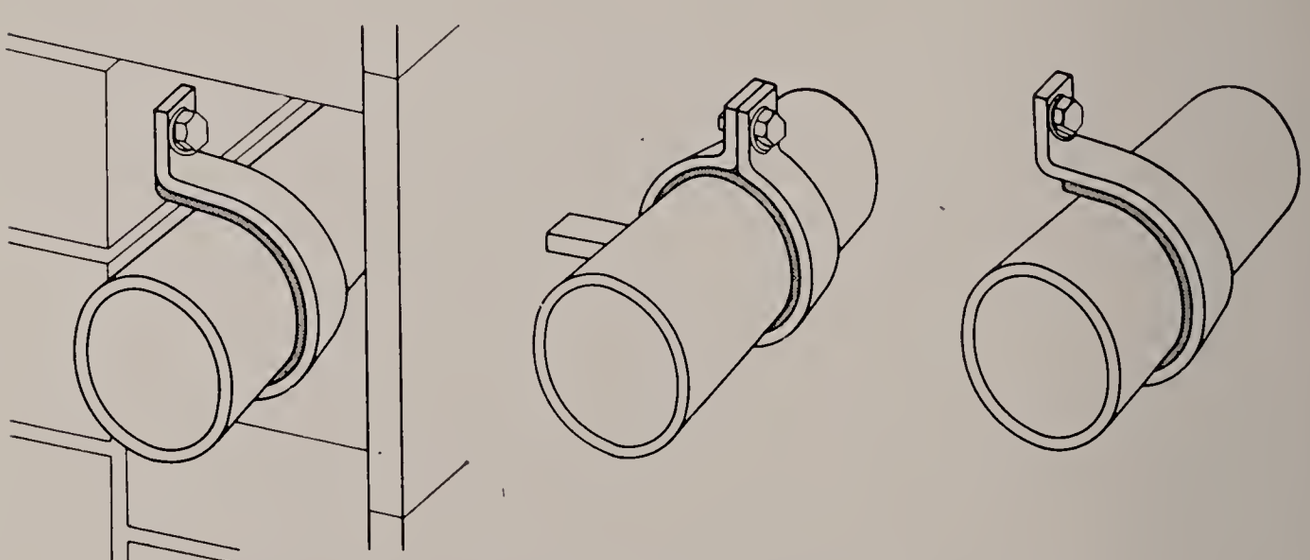


FIG. XIV/21.—Alternative methods for fixing pipe clips.

XIV/22 shows various forms of hangers and clips. Local support must be provided for heavy fittings (valves). Positioning can be effected by means of P.V.C. lugs which are welded or cemented on. Good alignment is essential to prevent stresses and jamming. Care should also be taken to avoid stresses due to detachable connections, for

instance, screwed unions or fittings. A simple and reliable method for ascertaining stresses or their absence is by loosening some of the flanges, clips, etc., soon after assembly; the pipeline should then still retain its original position and shape.

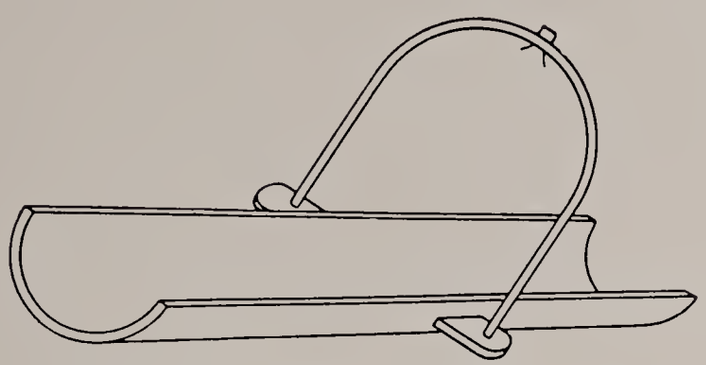


FIG. XIV/22.—Pipe hanger: stirrup type.

The distance between the individual clips, hangers, etc., depends on the size and wall thickness of the pipe and the temperature of the liquid or gas passing through as well as the ambient temperature in the room where the pipeline is to be installed. In general, support should be given at 3 to 4 ft. intervals. In all cases where the temperature exceeds 105° F. (40° C.) continuous support is required; this also applies to pipelines which are exposed in such a way that they are liable to mechanical damage. Continuous support can be provided by troughs fabricated from waste material (off-cuts, etc.) mainly timber. Alternatively, light gauge steel pipes can be cut lengthwise and both halves may then be used.

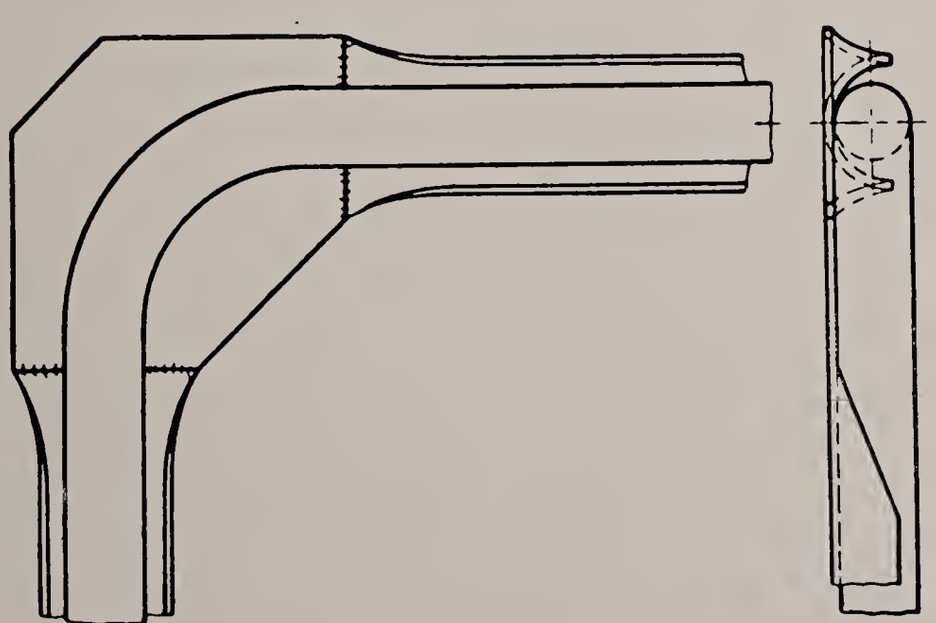


FIG. XIV/23.—P.V.C. bend in tubular metal trough.

The installation of troughs for expansion pieces and bends requires great care to ensure free movement. Fig. XIV/23 shows a 90° bend

in a tubular trough fabricated from metal, Fig. XIV/24 a timber trough for an expansion piece.

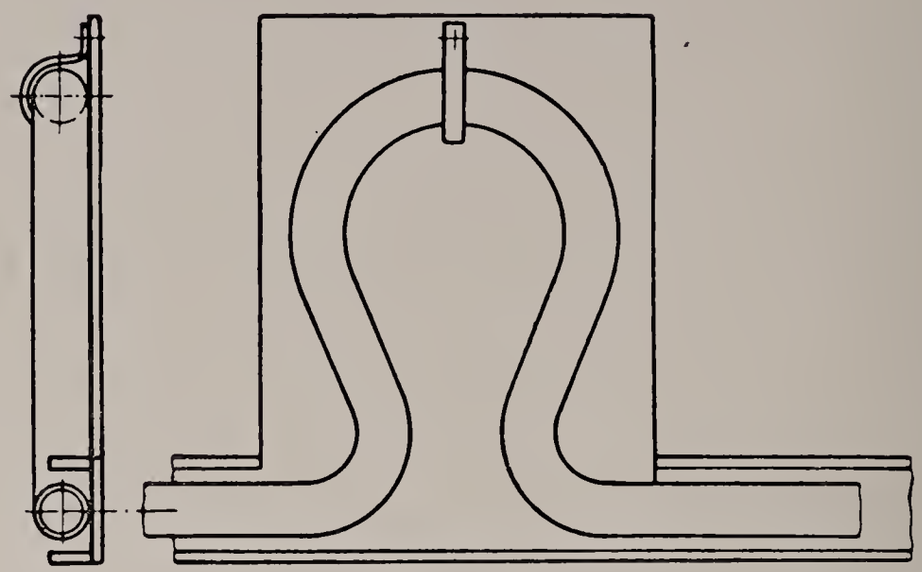


FIG. XIV/24.—P.V.C. expansion piece in timber trough.

Passage of P.V.C. pipes through walls and ceilings

P.V.C. pipes should not be cemented into walls or ceilings. Holes cut into walls for the passage of pipes should be at least $\frac{1}{2}$ in. larger in diameter than the pipe which should be wrapped round with cardboard or the like at the point of passing the wall. A metal or plastic pipe of a length corresponding to the thickness of the wall is then drawn over the P.V.C. pipe and firmly cemented into the wall. The P.V.C. pipe can move freely after withdrawal of the cardboard wrap. An alternative method is the fitting of two covers of plasticized P.V.C. (one on each side of the wall) with a tightly fitting cutout through which the pipe passes. The covers are then nailed to the wall.

Vertical pipes passing through a workshop or any other area which is freely accessible, should be encased up to a height of 3 ft. from the floor to protect them against damage.

Heavy fittings and valves in particular should be supported independently to eliminate stresses due to their operation or weight. Fig. XIV/25 illustrates alternative methods for the support of valves.

High pressure steel pipes lined with rigid polyvinyl chloride

Polyvinyl chloride has the advantage of being highly resistant to most chemicals, including concentrated acids, alkalis and oxidizing agents. It is sufficiently rigid and has reasonably good fatigue values. Its limitation, however, is the low mechanical strength at extreme temperatures. It is not recommended for use above 60° C., although it softens only noticeably at approximately 80° C. It becomes brittle at temperatures around 0° C. and has almost no elongation at −20° C

P.V.C. pipe lines are, therefore, extremely brittle when subjected to tension or shock at low temperatures and cannot sustain pressures above 40° C.

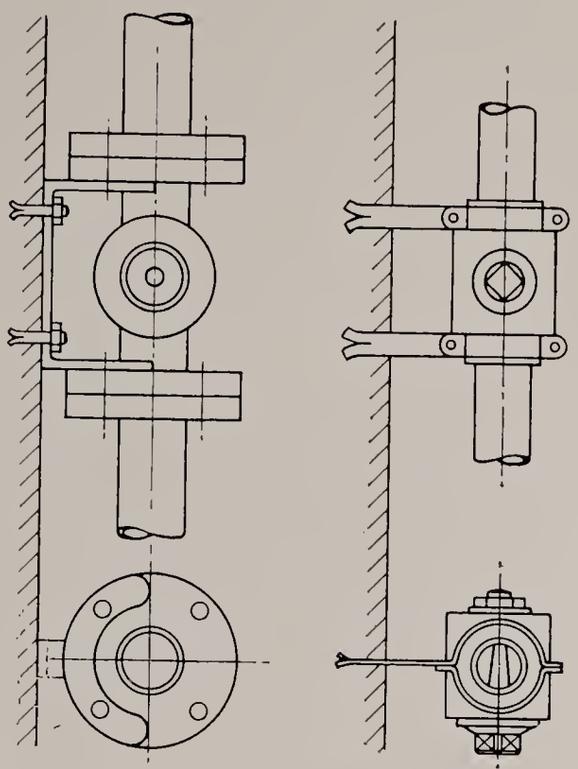


FIG. XIV/25.—Arranging for the proper support of P.V.C. valves.

It is therefore not surprising that many attempts have been made in the past to produce P.V.C. pipes strengthened by an outside support from a material which has greater mechanical strength (steel or aluminium). The solution of this problem is, however, not as simple as it sounds as P.V.C. has three times the thermal expansion of aluminium and seven times that of steel. Earlier attempts in this direction, i.e. drawing a metal pipe over the P.V.C. pipe, were unsuccessful as cracks occurred around the flanges at temperatures below the freezing point. A process patented by the Dynamit A.G. seems to have met with more success (*11*). The details of this process are rather complicated and are therefore not given in this book. It appears from the information available that P.V.C./metal pipes manufactured by this process remain firmly bonded even at temperatures as low as −60° C. Repeated impacts on the protecting metal sheath do no longer cause cracks or separation of the P.V.C. lining. This type of pipe is manufactured in a variety of sizes up to 5 in. diameter and can be used for pressures varying from 6 up to 25 atm. Another attractive feature of these P.V.C./metal pipes is their price as they are considerably cheaper than P.V.C. pipes of heavy wall section.

The fabrication of pipe lines using these newly developed P.V.C./metal pipes requires a special method, details of which are given below.

The two pipe ends to be jointed are cut square; the outer surface of both metal pipes is then roughened with emery paper for a length of approximately 1 in. measured from the abutting edges. A P.V.C. socket is then drawn over each pipe end and cemented to the pipe with a special type of quick setting cement. Once the cement has set the inner part of the P.V.C. lining is roughened with emery paper up to approximately 1 in. in depth (measured from the abutting edges) and a suitable lining made from rigid P.V.C. is then inserted and cemented to the P.V.C. lining leaving approximately 2 in. of the liner protruding from each end. These protruding ends are then flared so

that they lie firmly against the exposed surfaces of the loose flanges drawn over the sockets. (These loose flanges are either cut from rigid P.V.C. or from a phenolic material.) Gaskets made from plasticized P.V.C., Polythene and rigid P.V.C. are also employed.

Elbows and Tee-pieces up to 4 in. diameter are also available in the same composite material. Elbows and Tee-pieces larger than 4 in. bore are produced from split mouldings (steel) lined with rigid P.V.C.; the two halves are held together by screws or clamps.

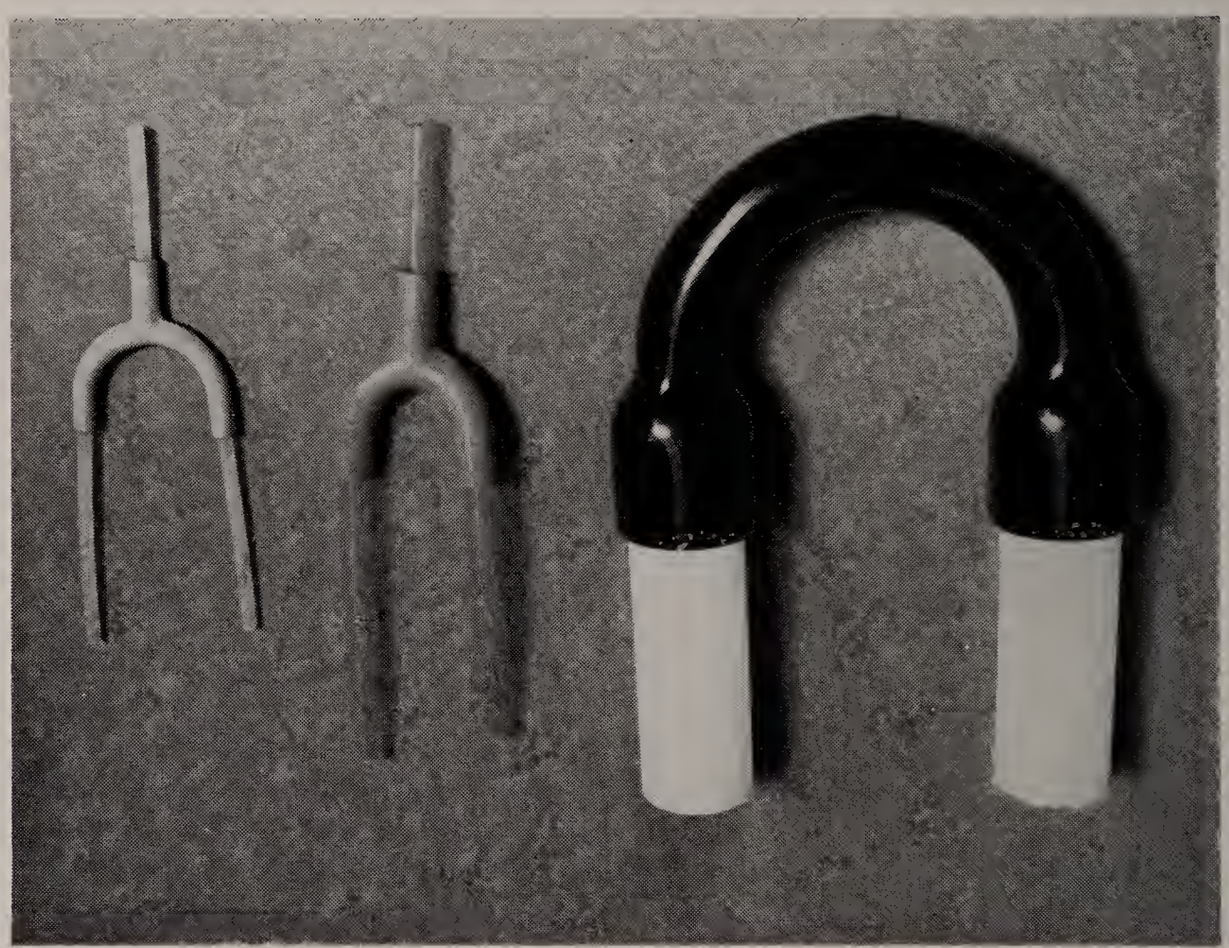


FIG. XIV/26.—Moulded connectors in plasticized P.V.C. for plasticized P.V.C. tubing.

Steel pipes lined with rigid P.V.C. on their inside are at present available in Germany and in the U.S.A. They are expected to find wide applications, for instance, in oil fields for carrying salt water and other corrosive liquids.

Steel or aluminium pipes with a protective lining of P.V.C. on their inside and a polythene lining on their outside can be produced by a patented extrusion process developed by an Italian firm.

Plasticized P.V.C. tubing

Plasticized P.V.C. tubing has many uses in industry and to a certain

extent in surgery, for instance, for blood transfusion equipment. In the latter case a non-toxic compound has to be employed.

Plasticized P.V.C. tubing is available in a wide variety of types and sizes—clear and pigmented—from $\frac{1}{8}$ in. bore to 2 in. bore.

Joints can be made by cementing or heated tool welding (butt-welds); alternatively moulded (plasticized P.V.C. fittings, see Fig. XIV/26) can be employed. The ends of the tubes are dipped into a suitable solvent, for instance methyl-ethylketone, and left there for a few seconds. They are then withdrawn and pushed into the fitting, yielding a permanent joint in a short time.

Special grades of plasticized tubing are made for use with petrol and conc. hydrogen peroxide (H.T.P.). Other grades (non-toxic) are used for fitting equipment for cold beverages (vending machines), milking machines, etc.

Braided, plasticized P.V.C. tubing is often employed for compressed air lines.

Flange covers and valve covers

Serious accidents occur here and there when pipe lines carrying acids and other corrosive liquids are first taken in use under full pressure. The most prominent sources of leaks are flanges and valves which are frequently not sufficiently tight; the corrosive liquids spurt in all directions causing damage to adjacent installations and sometimes also to the personnel.

Plastic flange covers and valve covers minimize accidents to a great extent; they can be deep drawn or vacuum-formed from rigid P.V.C., see Fig. XIV/27, or sewn from P.V.C. coated glass cloth. The latter type is also available with a coating containing indicators which, according to the nature of the liquid passing through the line, change the colour of the coating from red to yellow in the case of acids and from white to purple in the case of alkaline solutions. The first few drops of liquid squeezed out from a defective flange or from a leaking valve indicate failures at once by a vivid colour change, and enable the maintenance engineer to cure the trouble before real harm is done.

The protective covers are equally suitable for metal or plastic pipelines and fittings.

Polyvinyl chloride tape for the protection of metal pipes.

Metal pipes can be protected against corrosion by applying polyvinyl chloride/butyl rubber tapes, either by hand or, for large scale applications, by special winding machines. This procedure stops moisture migration and provides also high resistance to soil corrosion. Coloured tapes can be used for pipe identification.

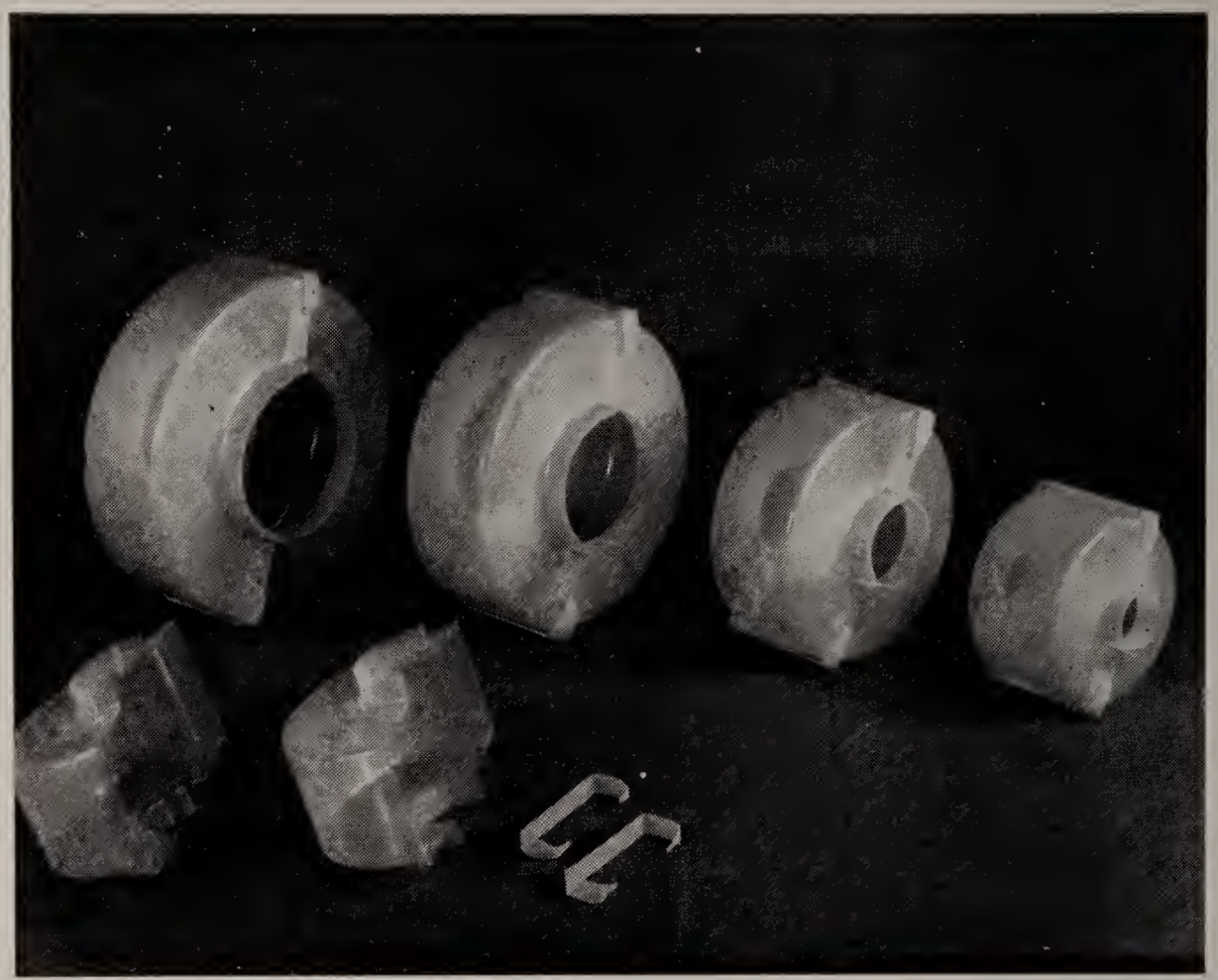


FIG. XIV/27.—Flange covers deep drawn from rigid P.V.C. foil.

Identification of P.V.C. pipe lines

Rigid P.V.C. pipes should not be painted to allow for their identification, i.e., they should be recognizable as such. A case is known where workmen mistook a P.V.C. pipe line for one of steel because of the colour and leaned a heavy stepladder against it. The P.V.C. pipe line cracked under the heavy weight with disastrous results.

Planning of P.V.C. pipe lines

Proper planning greatly assists in the fabrication of rigid P.V.C. pipe lines. The following steps should be observed:

(1) Check whether the P.V.C. is a suitable material from the corrosion point of view (see tables provided).

(2) Ascertain the temperature limits from the customer and calculate expansion and contraction.

(3) Ascertain the ultimate tensile strength at the maximum temperature which might apply and select tubing of the correct wall thickness.

Very few problems arise when the temperature in the room where a P.V.C. pipe line is installed is kept constant throughout the year, as

expansion or contraction will only be due to temperature differences in the liquid to be carried; however, if a pipe line is installed outside or in places where the temperature is very low in winter and reasonably high in summer, installation should be preferably carried out during spring or autumn.

(4) Allow for sufficient expansion pieces.

(5) Provide sufficient support at reasonable intervals, or better still, provide support right through. Continuous support must be given where pipe lines work at temperatures higher than 120° F.

(6) Use great care when applying clips and pipe hangers.

(7) Consider smaller bore pipe lines laid in parallel instead of large bore tubing whenever possible. This alternative is not only cheaper but also more satisfactory in use.

Every pipe line contains fixed points. The proper lay-out and the arrangement for these fixed points requires a great deal of experience. It is, for instance, possible to use elbows as fixed points and to provide expansion pieces at suitable intervals. This is a better solution than the provision of a fixed point right in the centre of a pipe line and to apply expansion joints on either side.

An interesting paper relating to suitable methods for the assembly of pipe lines was published by Minikus (*8*), who discusses the assembly of pipes by means of +GF+fittings. He recommends the use of special specification-and-lay-out forms, which facilitate calculations in the drawing office and also permit the fabrication of the individual

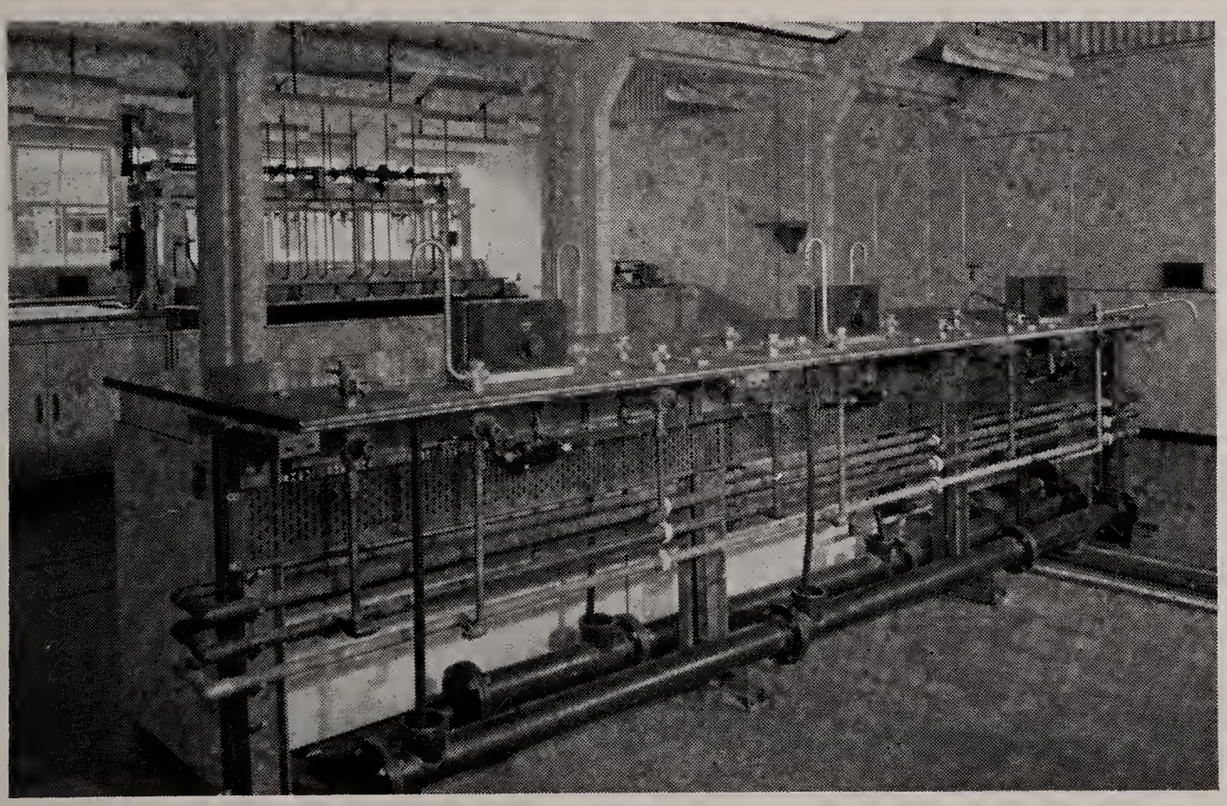


FIG. XIV/28.—Drainage system in laboratory bench.

pipe sections in the workshop to a high degree of accuracy, cutting down the work on site to a minimum.

It is, of course, necessary to employ standardized fittings with specified sockets of known depth to avoid variations in length.

Typical applications: The chemical industry

The chemical industry in its fullest sense is still the largest user of rigid P.V.C. pipes. New uses and new applications are found almost daily in an expanding field.

A few of the more unusual applications are shown below; it should, however, be mentioned that they represent a very small selection from an extremely large collection of known applications.

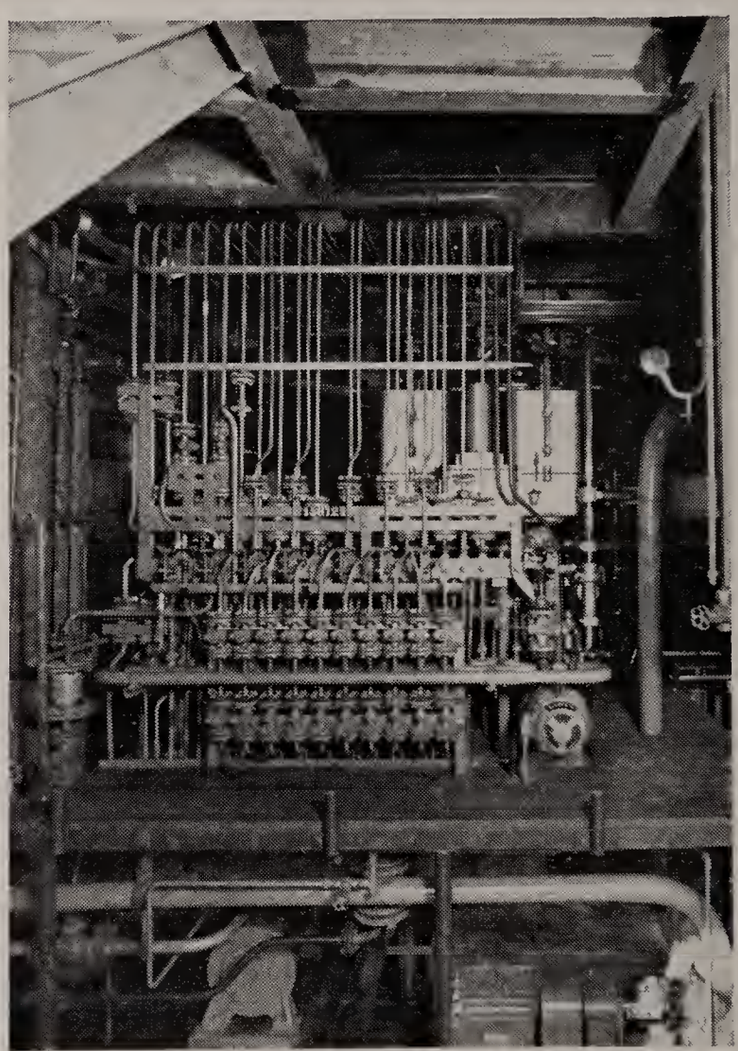


Fig. XIV/29.—Control unit on papiermâché machine.

Fig. XIV/28 shows the P.V.C. drainage system for a laboratory bench. Four individual pipe units are used to build up a variety of connections. Fig. XIV/29 illustrates the P.V.C. pipework used on the distribution system of a papiermâché machine. Fig. XIV/30 shows a large P.V.C. cooling coil being manufactured.

Other types of cooling coils are shown in Figs. XIV/31 and XIV/32.

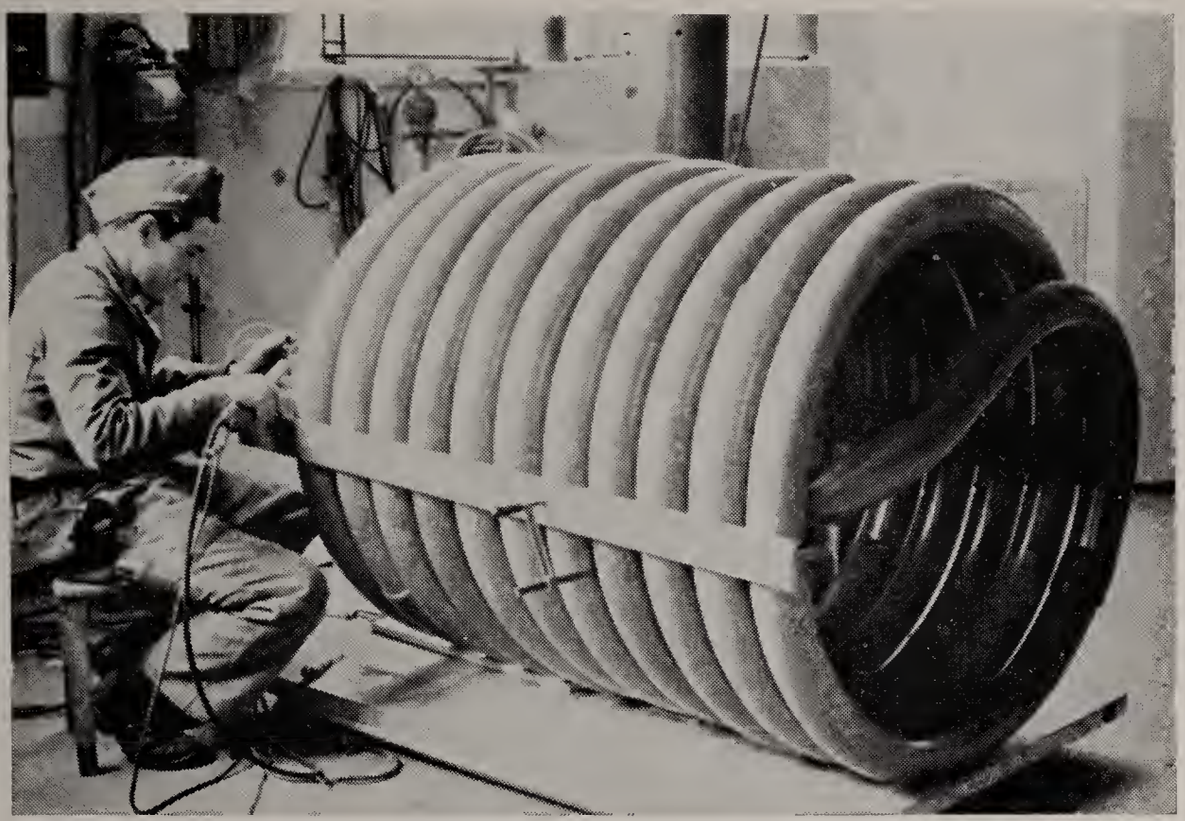


FIG. XIV/30.—Large cooling coil fabricated from 3 in. bore P.V.C. pipe.

FIG. XIV/31.—Rectangular P.V.C. cooling coil.

Cold water services

Rigid P.V.C. pipes are used on a large scale for the installation of cold water service lines in Holland and in Japan. In most other parts of the world, polythene pipes are preferred for this application.

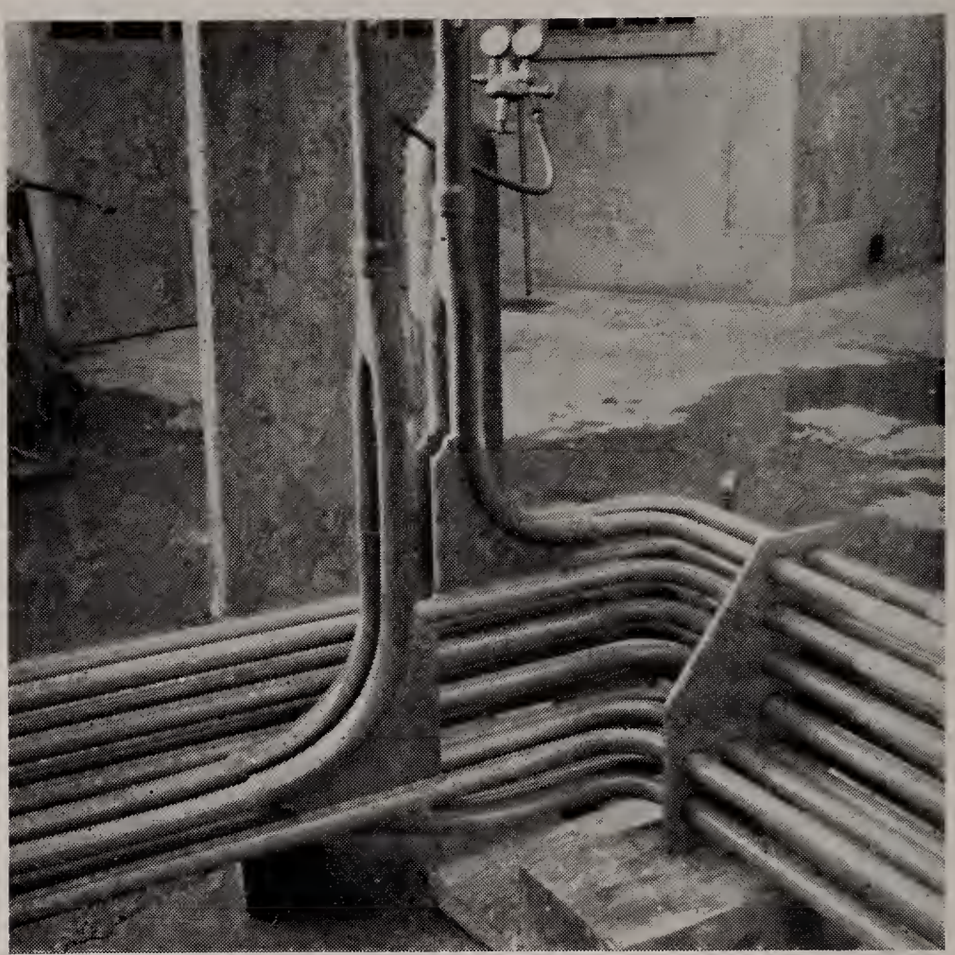


FIG. XIV/32.—Details of cooling coil shown in Fig. XIV/31.
Note.—Spacing arrangement between the individual pipes.

Rigid P.V.C. pipes for beer cellars and wine vaults

Rigid P.V.C. pipes are widely used in German public houses to carry beer from the cellars to the tap. French vintners make extensive use of P.V.C. pipes in their wine cellars. P.V.C. installations of this kind have not yet been reported from other countries; apparently, polythene tubing is preferred by breweries in Great Britain whilst American wine cellars are equipped with cellulose acetate-butyrate tubing.

Rigid P.V.C. pipes are eminently suitable for these applications provided they do not contain toxic stabilizers or plasticizers. Most pipe manufacturers can nowadays supply a non-toxic type of pipe. Thorough tests by Prof. Fink of the Institute for Fermentation Technology at the University of Cologne have proved without doubt that rigid P.V.C. is not attacked by beer, wine or fruit juices, neither does it

impair the taste of these. (Most metals—stainless steel excepted—are attacked by the acids contained in fruit juices.) Electrolytic attack, caused by stray currents which often occur in refrigerated cellars, does not harm P.V.C. pipes which is also to their advantage.

Rigid P.V.C. beer lines are easy to clean. Their smooth surface prevents the formation of scale, neither can bacteria grow on them as they do in the case of metal pipes. Cleaning should be effected by means of chemical solutions and not by 'steaming'.

Connections are usually made by means of cemented bell and spigot joints except the taps which are screwed on with unions. Details of a suitable arrangement are shown in Fig. XIV/33. From this it can be seen that coiling of the pipe is recommended to allow for expansion and contraction. The coil is preferably suspended from the ceiling by means of a rigid P.V.C. spring.

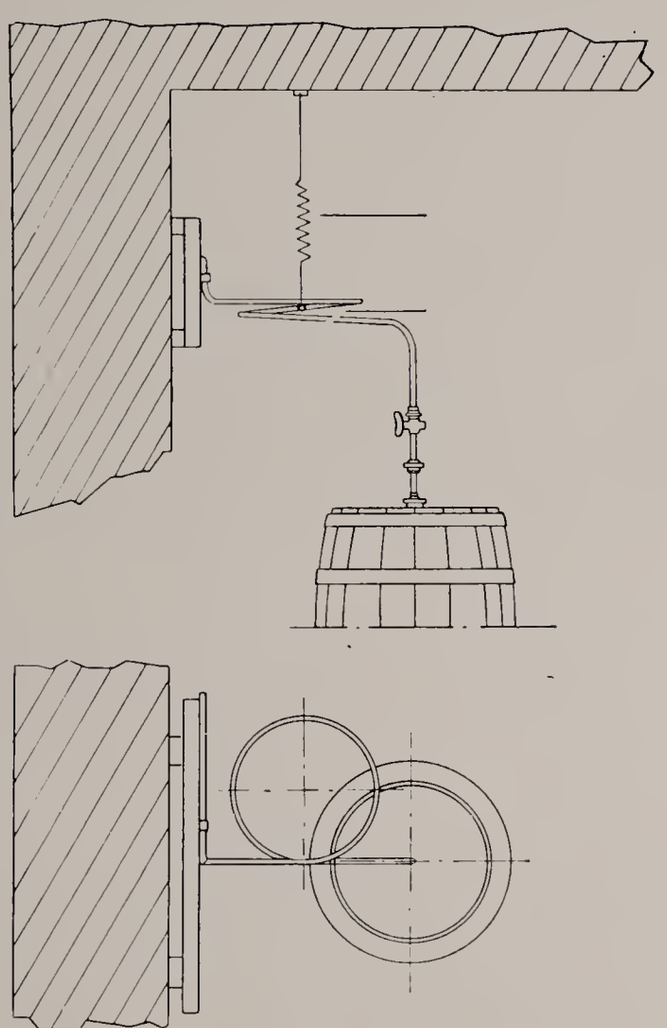


FIG. XIV/33.—P.V.C. coil line suspended from the ceiling by means of a P.V.C. spring.

Fig. XIV/34 shows P.V.C. pipe connections attached to a wine reservoir.

P.V.C. conduit tubing

Rigid P.V.C. tubing of thin wall competes successfully with metallic conduits over which it has many advantages. It does not corrode and

can be laid underground or buried in lime, plaster and concrete. A reduced voltage drop can be noticed with P.V.C. conduits at higher frequencies (1,000 c.p.s. and over). The voltage drop with metallic conduits is quite noticeable. Apart from conduit of round and oval cross-section, channelling, fittings, adaptor boxes and lids are also available in rigid P.V.C.

FIG. XIV/34.—P.V.C. pipe lines in a wine cellar.

P.V.C. conduits to conform to I.E.E. Wiring Regulations No. 1301/5 for non-metallic conduits are now produced in Great Britain. Similar tubing is fully approved in Germany and Holland.

Standards

Standards for rigid P.V.C. pipes are now in preparation in many countries. German, Swiss and Dutch tentative standards have been published whilst British standards will soon be available. Details of these tentative standards and some notes referring to the practices of laying P.V.C. pipes can be found in the Appendix.

PIPE STANDARDS AND PIPE LAYING PRACTICES IN VARIOUS COUNTRIES

American practice and standards

American and Canadian P.V.C. pipes are produced to the same standards. Ordinary type P.V.C. and high impact P.V.C. are available in Schedule 40 and Schedule 80 (extra heavy wall thickness).

These tables (VIII, IX and X) show the bursting pressures at 80° F. (27° C.). The recommended operating pressure at 75° F. (24° C.) is approximately 20 per cent. that of the bursting pressure. The graphs shown on page 200 indicate the maximum operating pressure at any practicable temperature. To find the maximum operating pressure at a given temperature proceed as follows: Find maximum operating pressure at 75° F. at lower scale, draw a line until you reach the line representing the desired temperature and proceed parallel to the bottom line, until you reach vertical line indicating pressure.

AMERICAN STANDARD RIGID P.V.C. PIPES

Table VIII

Schedule 40

Pipe Size (I.P.S.)	*O.D.*	*I.D.*	*Wall Thick-ness*	*Ord. P.V.C*		*High Imp:*	
				Lb. per ft.	**Burst Pressure* 80° F. *P.S.I.*	*Lb. per ft.*	**Burst Pressure* 80° F. *P.S.I.*
¼ in.	·540	·364	·088	·075	2280	·073	1955
⅜ in.	·675	·493	·091	·100	1890	·098	1620
½ in.	·840	·622	·109	·150	1816	·146	1557
¾ in.	1·050	·824	·113	·199	1506	·195	1291
1 in.	1·315	1·049	·133	·295	1416	·289	1214
1¼ in.	1·660	1·380	·140	·400	1180	·391	1012
1½ in.	1·900	1·610	·145	·477	1068	·467	916
2 in.	2·375	2·067	·154	·643	907	·629	778
2½ in.	2·875	2·469	·203	1·020	988	·998	847
3 in.	3·500	3·068	·216	1·333	864	1·304	741
3½ in.	4·000	3·548	·226	1·601	791	1·566	678
4 in.	4·500	4·026	·237	1·898	737	1·856	632
5 in.	5·563	5·047	·258	2·574	650	2·518	557
6 in.	6·625	6·065	·280	3·340	591	3·267	507
8 in.	8·625	7·981	·322	5·023	505	4·914	433
10 in.	10·750	10·020	·365	7·259	474	7·101	407
12 in.	12·750	11·838	·406	9·398	445	9·194	382

DO NOT THREAD—(Use with Socket or Belled Type Fitting Only.)
*Recommended Working Pressure is 20 per cent. of Burst Pressure.

Apart from Schedules 40 and 80, pipes are also made in accordance with Schedules 5, 120 and 160, but these are less frequently used.

Pipes are supplied in 10 ft. random lengths, but longer lengths (20 ft.) can be supplied against orders.

Schedule 40 pipes are used with plain ends only as the relatively thin wall does not allow for threading. Schedule 80 and 120 pipes are supplied with plain ends or threaded.

Typical American pipe fittings are shown in Fig. XIV/6.

British practice and standards

A number of British pipe standards are at the present time being prepared by several committees and some of these standards will be published in the near future.

TABLE IX

SCHEDULE 80

Pipe Size (I.P.S.)	*O.D.*	*I.D.*	*Wall Thick-ness*	*Ord. P.V.C.*		*High Imp:*	
				Lb. per ft.	**Burst Pressure 80° F. P.S.I.*	*Lb. per ft.*	**Burst Pressure 80° F. P.S.I.*
¼ in.	·540	·302	·119	·094	3085	·092	2640
⅜ in.	·675	·423	·126	·130	2515	·127	2240
½ in.	·840	·546	·147	·192	2450	·187	2100
¾ in.	1·050	·742	·154	·259	2053	·254	1760
1 in.	1·315	·957	·179	·382	1905	·374	1633
1¼ in.	1·660	1·278	·191	·527	1611	·516	1381
1½ in.	1·900	1·500	·200	·639	1473	·625	1263
2 in.	2·375	1·939	·218	·883	1284	·864	1101
2½ in.	2·875	2·323	·276	1·346	1344	1·317	1152
3 in.	3·500	2·900	·300	1·804	1200	1·764	1029
3½ in.	4·000	3·364	·318	2·202	1113	2·155	954
4 in.	4·500	3·826	·337	2·634	1049	2·577	899
5 in.	5·563	4·813	·375	3·658	944	3·579	809
6 in.	6·625	5·761	·432	5·026	912	4·917	782
8 in.	8·625	7·625	·500	7·632	784	7·467	695

*Recommended Working Pressure is 20 per cent. of Burst Pressure.

The following standards are now in preparation:

B.S. for unplasticized P.V.C. tubes and copolymers thereof.

B.S. for high impact P.V.C. tubing, and

B.S. for plasticized P.V.C. tubing.

The most important of these standards will be the one for unplasticized P.V.C. tubes for general purposes, including the Food Industry.

Distinction is made between unplasticized P.V.C. pipes and other types containing up to 5 per cent. of suitable copolymers. Pipes for the food industry and other specialized uses are dealt with separately.

The standards will give details concerning the composition of the compounds, dimensions of the pipes, their mechanical properties, details of testing, machinery, forming and jointing (welding or cementing); they will also contain recommendations concerning suitable types of joints. A comprehensive list of chemicals and their behaviour towards rigid (unplasticized) P.V.C. will be found of great value to designers and users of P.V.C. pipes, etc.

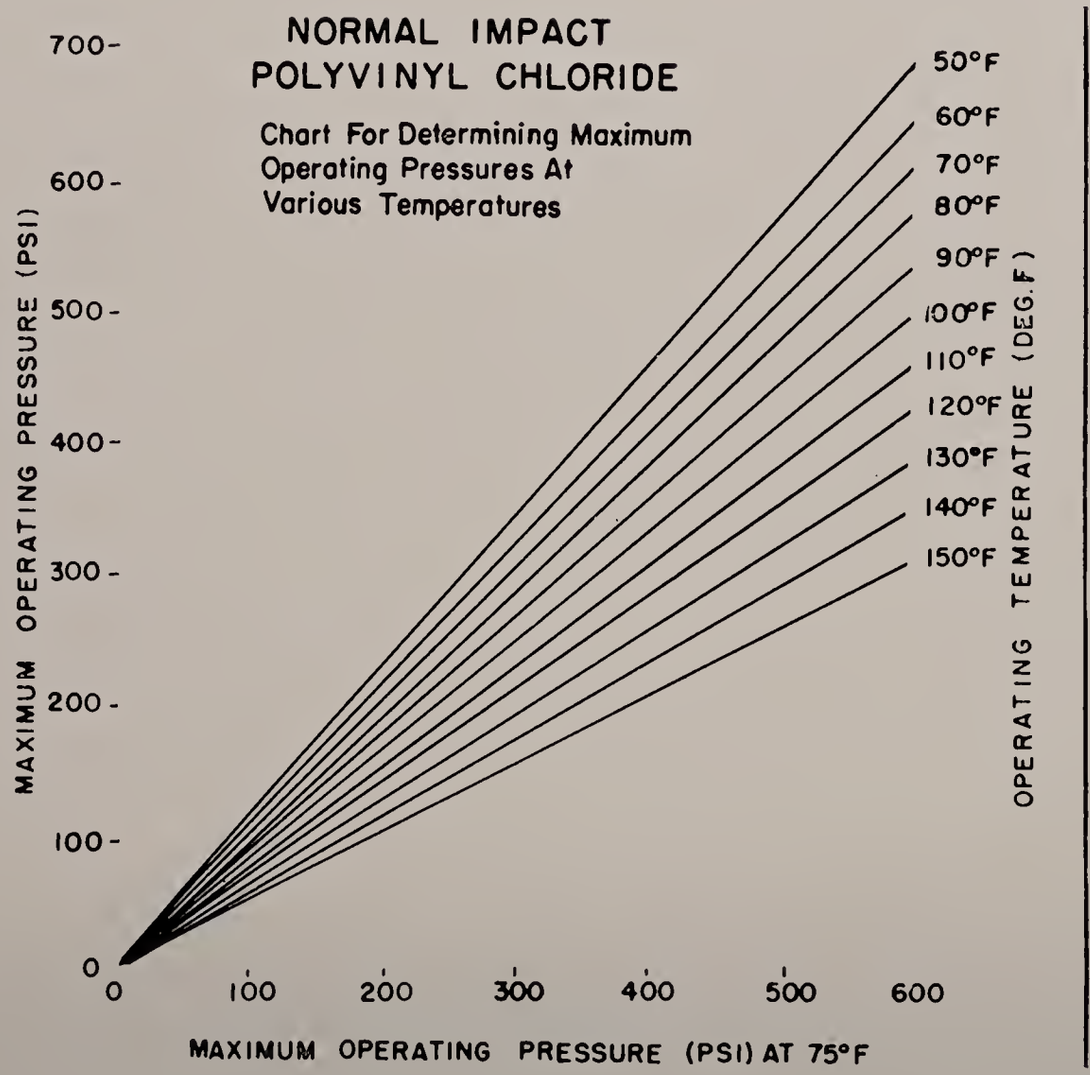
TABLE X

SCHEDULE 120

Pipe Size (*I.P.S.*)	*O.D.*	*I.D.*	*Wall Thick-ness*	*Ord. P.V.C.*		*High Imp:*	
				Lb. per ft.	**Burst Pressure* 80° F. *P.S.I.*	*Lb. per ft.*	**Burst Pressure* 80° F. *P.S.I.*
½ in.	·840	·500	·170	·214	2834	·209	2429
¾ in.	1·050	·710	·170	·281	2269	·275	1943
1 in.	1·315	·915	·200	·419	2129	·410	1825
1¼ in.	1·660	1·230	·215	·584	1813	·571	1554
1½ in.	1·900	1·450	·225	·708	1658	·692	1421
2 in.	2·375	1·875	·250	·998	1473	·976	1263
2½ in.	2·875	2·275	·300	1·452	1460	1·420	1252
3 in.	3·500	2·800	·350	2·071	1400	2·026	1200
3½ in.	4·000	3·300	·350	2·400	1225	2·348	1050
4 in.	4·500	3·626	·437	3·334	1360	3·262	1165
5 in.	5·563	4·563	·500	4·752	1258	4·649	1079
6 in.	6·625	5·501	·562	6·402	1188	6·263	1018

*Recommended Working Pressure is 20 per cent. of Burst Pressure.

TABLE XI


NORMAL IMPACT
POLYVINYL CHLORIDE
Chart For Determining Maximum
Operating Pressures At
Various Temperatures
MAXIMUM OPERATING PRESSURE (PSI)
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
MAXIMUM OPERATING PRESSURE (PSI) AT 75°F
OPERATING TEMPERATURE (DEG.F)
50°F
60°F
70°F
80°F
90°F
100°F
110°F
120°F
130°F
140°F
150°F

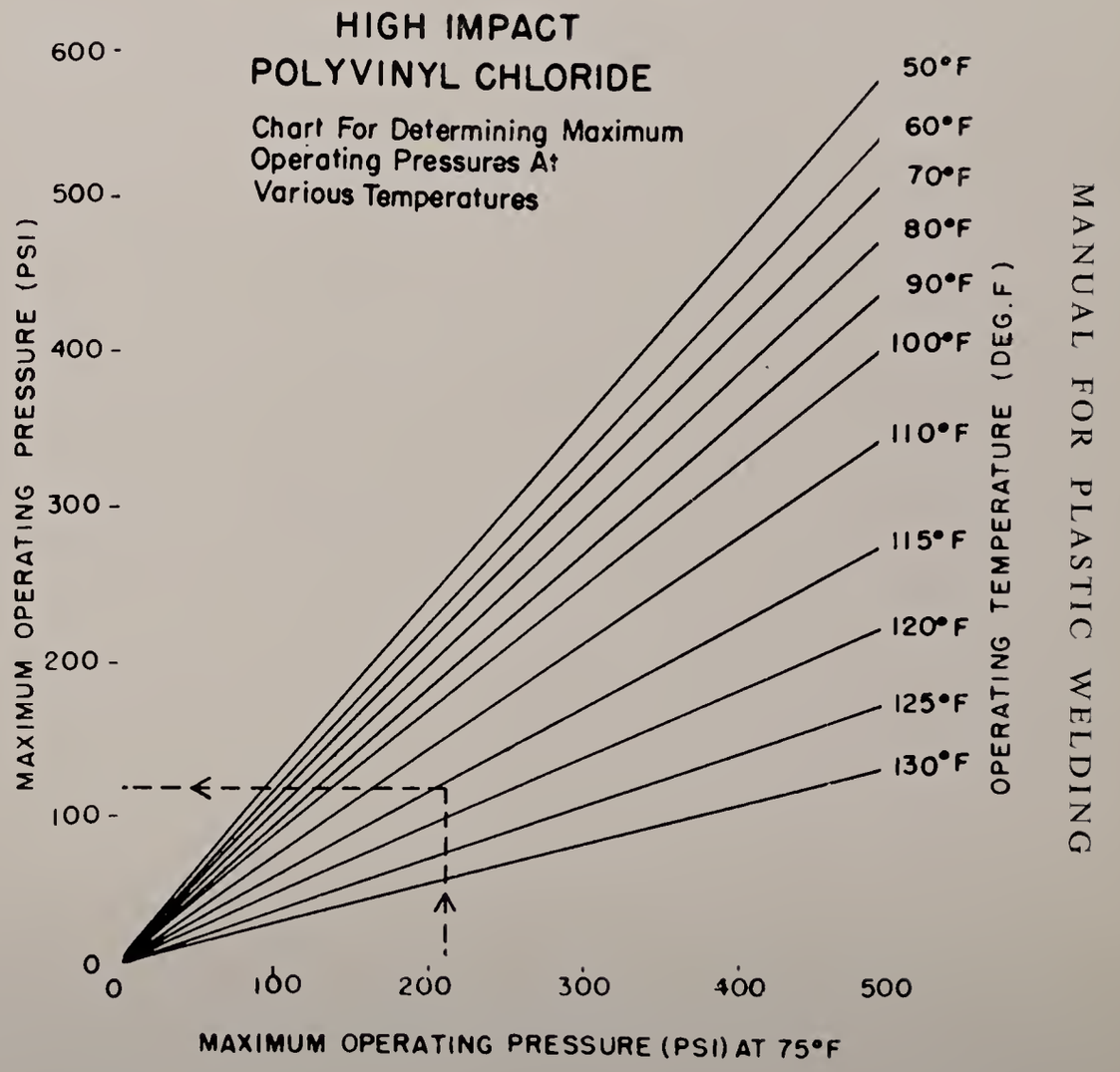

HIGH IMPACT
POLYVINYL CHLORIDE
Chart For Determining Maximum
Operating Pressures At
Various Temperatures
MAXIMUM OPERATING PRESSURE (PSI)
600
500
400
300
200
100
0
0
100
200
300
400
500
MAXIMUM OPERATING PRESSURE (PSI) AT 75°F
OPERATING TEMPERATURE (DEG.F)
50°F
60°F
70°F
80°F
90°F
100°F
110°F
115°F
120°F
125°F
130°F

Table XII

Dimensions of British Rigid P.V.C. Tubing showing Tolerances on O.D. and Wall

Nominal O.D. *Inches*	*Minimum O.D. (gauge diam. of thread)* *Inches*	*Maximum O.D. (·008 in. +1·01 in. min. O.D.)* *Inches*	*Tubes for Cemented Joints*				*Tubes for Screwing Joints*			
			Wall for 142 lb./sq. in.		*Wall for 57 lb./sq. in.*		*Wall for 142 lb./sq. in.*		*Wall for 57 lb./sq. in.*	
			Min.	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*	*Min.*	*Max.*
0·406 (13/32)	·383	·395	·039	·051	·039	·051	·056	·068	·040	·052
0·531 (17/32)	·518	·531	·041	·053	·039	·051	·075	·090	·055	·068
0·688 (11/16)	·656	·671	·052	·065	·039	·051	·087	·104	·060	·076
0·844 (27/32)	·825	·841	·065	·080	·039	·051	·111	·130	·078	·094
1·063 (1 1/16)	1·041	1·059	·082	·098	·039	·051	·128	·149	·086	·103
1·344 (1 11/32)	1·309	1·330	·103	·121	·043	·055	·156	·180	·103	·121
1·688 (1 11/16)	1·650	1·675	·129	·150	·054	·067	·190	·217	·122	·142
1·906 (1 29/32)	1·882	1·909	·147	·170	·062	·076	·208	·237	·129	·150
2·375 (2 3/8)	2·347	2·378	·183	·209	·077	·093	·246	·279	·146	·169
3·000 (3)	2·960	2·998	·231	·262	·097	·115	·296	·334	·169	·194
3·500 (3 1/2)	3·460	3·503	·270	·305	·113	·132	·336	·378	·187	·214
4·000 (4)	3·950	3·998	·308	·347	·129	·150	·377	·423	·206	·235
4·500 (4 1/2)	4·450	4·503	·347	·390	·146	·169	·418	·468	·225	·256
5·500 (5 1/2)	5·450	5·513	·424	·474	·178	·204	·500	·558	·263	·297
6·500 (6 1/2)	6·450	6·523	·502	·560	·211	·240	·582	·648	·300	·338

(Courtesy of Yorkshire Imperial Metals Ltd.)

Calculation of working stresses

The permissible working stresses in the new British Standards have been worked out using the following formula:

$$S = \frac{P \times (De - W)}{2W}$$

where P is the working pressure in p.s.i.
W is the wall thickness and
De is the external diameter of the pipe.

The stress values are based on 60 kg./cm.^{2}=853 p.s.i. The outside diameters of the pipes will comply with B.S.1387 for steel pipes or I.S.O./T.C.5. steel standards both of which are interchangeable.

The use of machined or hand-cut threads is not recommended although moulded threads are considered acceptable.

Threading of high impact P.V.C. pipes for which standards are also in preparation will be acceptable.

Table XII on page 201 shows details of rigid P.V.C. pipes now being produced on a commercial scale in Great Britain. The sizes given are most likely in compliance with those in the new British P.V.C. Pipe Standards. A further range of sizes is contemplated to enable users to employ fittings of continental origin, alternatively to allow for the sale of pipes manufactured in Great Britain to users on the Continent.

Moulded fittings are being produced by at least three British firms.

German practice and standards

German Standards for rigid P.V.C. pipes were first issued in July, 1941 (DIN 8062). They were revised in September, 1951 and again modified in August, 1957, when the present tentative standards DIN 8062 were offered for comments (Table XIII).

Details of the dimensions, etc., are shown below. Altogether, three different types are standardized: light, medium and heavy weight. The modifications concern mainly the figures for outside diameter, and the wall thickness which were changed to comply with the recommendations of the I.S.O. Sub-Committee TC.5/SC.6.

All pipes are now specified by quoting their outside diameters and their wall thickness.

P.V.C. pipe 32×2·6 DIN 8062 for instance, is a rigid P.V.C. pipe of 32 mm. outside diameter and 2.6 mm. wall thickness in accordance with Standard DIN 8062.

A permissible stress of not less than 60 kg./cm.^{2} was chosen for calculating the wall thickness of the pipes listed in DIN 8062.

Apart from DIN 8062, there are further standards for the fabrication of P.V.C. pipes and pipe lines and also for their application and use. These were originally issued as DIN 8061, Section 1, 2 and 3 which are at present undergoing revision. Tentative Standard DIN 16928 (May,

Table XIII

Tentative German Standards for Rigid P.V.C. Pipes (Din 8062) August, 1957.

Nom. Bore	*Outside Dia.*		*Light Weight*			*Medium Weight*			*Heavy Weight*		
			Wall thickness		*Weight*	*Wall thickness*		*Weight*	*Wall thickness*		*Weight*
mm.	*d. mm.*	*tol. mm.*	*mm.*	*tol. mm.*	*kg./m.*	*mm.*	*tol. mm.*	*kg./m.*	*mm.*	*tol. mm.*	*kg./m.*
3	5	+0·4	—	—	—	—	—	—	1·0	+0·3	0·019
4	6	+0·4	—	—	—	—	—	—	1·0	+0·3	0·025
5	8	+0·45	—	—	—	—	—	—	1·0	+0·3	0·035
6	10	+0·45	—	—	—	1·0	+0·3	0·045	1·6	+0·35	0·064
8	12	+0·5	1·0	+0·3	0·055	1·6	+0·35	0·080	1·8	+0·4	0·088
10	16	+0·55	1·0	+0·3	0·075	1·6	+0·35	0·111	1·8	+0·4	0·123
15	20	+0·6	1·6	+0·35	0·143	1·8	+0·4	0·158	2·0	+0·4	0·172
20	25	+0·7	1·6	+0·35	0·182	1·8	+0·4	0·201	2·0	+0·4	0·221
25	32	+0·8	1·8	+0·4	0·263	2·0	+0·4	0·288	2·6	+0·45	0·363
32	40	+0·9	1·8	+0·4	0·333	2·0	+0·4	0·366	3·2	+0·5	0·556
40	50	+1·05	2·0	+0·4	0·463	2·6	+0·45	0·587	4·0	+0·6	0·864
50	63	+1·25	2·6	+0·45	0·749	3·2	+0·5	0·906	5·0	+0·7	1·36
65	75	+1·45	2·6	+0·45	0·898	3·6	+0·55	1·21	5·9	+0·8	1·90
80	90	+1·65	2·9	+0·5	1·20	4·5	+0·65	1·81	7·1	+0·9	2·74
100	110	+1·95	3·2	+0·5	1·62	5·4	+0·75	2·65	8·8	+1·1	4·14
110	125	+2·2	3·6	+0·55	2·07	5·9	+0·8	3·29	—	—	—
125	140	+2·4	4·0	+0·6	2·57	7·1	+0·9	4·40	—	—	—
150	160	+2·7	4·0	+0·6	2·95	8·0	+1·0	5·66	—	—	—

(The pressure rating given applies for temperatures up to 40°C max.)

1958) previously DIN, 8061, Section 2 (1954) deals with fabrication methods such as bending, cementing and welding. It contains details of suitable pipe joints (bell and spigot joints, sleeved butt-welded joints, and screwed joints using stub-end collars and metal. Fixed flanges are no longer considered suitable and loose flanges, with stub-end collars or conical collars are recommended in their place.

DIN 16928 contains also details of expansion pieces, instructions for fixing the pipes and their suspension; underground P.V.C. pipe lines should be laid sufficiently deep to eliminate frost. Embedding in sand is recommended for cases where the pipe lines have to be laid in rocky ground.

DIN 16929 (September, 1957) is still in its tentative form. It will finally replace DIN 8061, Section 3 (1954). It contains a comprehensive list of chemical reagents which have been tested to ascertain whether they have any influence on rigid P.V.C.; recommendations are also given for the maximum pressures which can be applied with safety in continuous use.

DIN 8063 (1941) deals with P.V.C. pipe bends whilst DIN 8064 (1941) DIN 8065 (1941), DIN 8066 (1947) and DIN 8067 (1941) give details of P.V.C. elbows, T-pieces, screwed joints and flanged connections.

Fittings are, in the majority of cases, of the fabricated type; some of the smaller size fittings are now also available in the form of injection mouldings.

Attention should also be drawn to VDI.2010 (April, 1944) issued by the VDI. Fachausschuss (Committee) for plastic materials. It contains recommendations and suggestions for the construction and design of P.V.C. pipe lines. These recommendations are in certain respects much more detailed than those in DIN 8061, in others they are no longer up-to-date.

Continental practice and standards

Various continental countries are at the present time finalizing their P.V.C. pipe standards (France, Holland, Switzerland). Most of these use a stress value of 60 kg./cm.^{2} (at 20° C.) for their calculations, except Holland, where 80 kg./cm^2 has been accepted as the permissible stress value.

Screwed bell and spigot joints are common practice in Holland and reports indicate that many thousands of these joints have given satisfaction in continuous use over many years provided great care is taken in their execution. Screwed bell and spigot joints are not foreseen in any other standards at present under consideration, although their successful application in Holland might lead to a change in standard practice in other countries later on.

Some continental countries also permit the incorporation of small amounts of plasticizers into the extrusion compound to reduce the brittleness of the pipes.

International standards

The International Standards Organization (I.S.O.) which meets frequently is preparing P.V.C. pipe standards which in time will most probably be accepted by most countries.

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CHAPTER XV

POLYVINYL CHLORIDE DUCT LINES

Duct lines in rigid polyvinyl chloride

Rigid P.V.C. duct lines for corrosive gases and fumes now seriously compete with metallic ducts, especially in chemical factories and in the electro-plating industry.

It has frequently been proved that P.V.C. ducts are cheaper in the long run—although their initial costs are often higher than those of metal ducts.

Savings are also made in consequence of the elimination of painting and maintenance; the only serious drawback to P.V.C. duct lines is their temperature limitation, restricting their use to applications where the temperature of the fumes passing through remains below 165° F. (75° C.).

Round ducts

Circular P.V.C. ducts are installed in most cases—although square ducts are generally cheaper in production—a fact which is often overlooked.

Ducts up to 14 in. bore are fabricated from standard tubing (extruded) which is nowadays available from stock in most industrial countries. (Some factories offer even larger bore tubing—up to 18 in. —but these are not regular production lines.)

Tubing larger than 18 in. bore has to be fabricated from rigid P.V.C. sheet by heat forming and welding; details of the methods used and information regarding the moulds are given below.

Material

Rigid, unplasticized sheet of $\frac{1}{8}$ in. thickness is used for tube sections up to 16 in. bore; for larger bore tubing $\frac{3}{16}$ in. or $\frac{1}{4}$ in. thick material should be used.

Method of fabrication

P.V.C. sheet of suitable thickness is marked off and cut to size, care being taken that the length or width of the sheet is approximately $\frac{3}{8}$ in. shorter when developed than the final circumference of the tube to be produced. The edges of the sheet are then chamfered with a file or, preferably, with a portable router; three lines are marked on the sheet, by chalk, dividing it into four parts of equal width, see

Fig. XV/1a. A soft flame from a bunsen burner or a gas torch is then quickly moved forward and backward along the first of these lines in order to soften the sheet for approximately 2 in. on each side of the line; care should be taken to avoid blistering or burning of the sheet. This operation is then repeated by preheating a zone of similar width on the other side of the sheet. The extreme ends of the sheet are then quickly folded over (two operators are required to do this efficiently) so that the abutting edges of the sheet run truly parallel with the centre line, see Fig. XV/1b. A provisional weld is now made with a

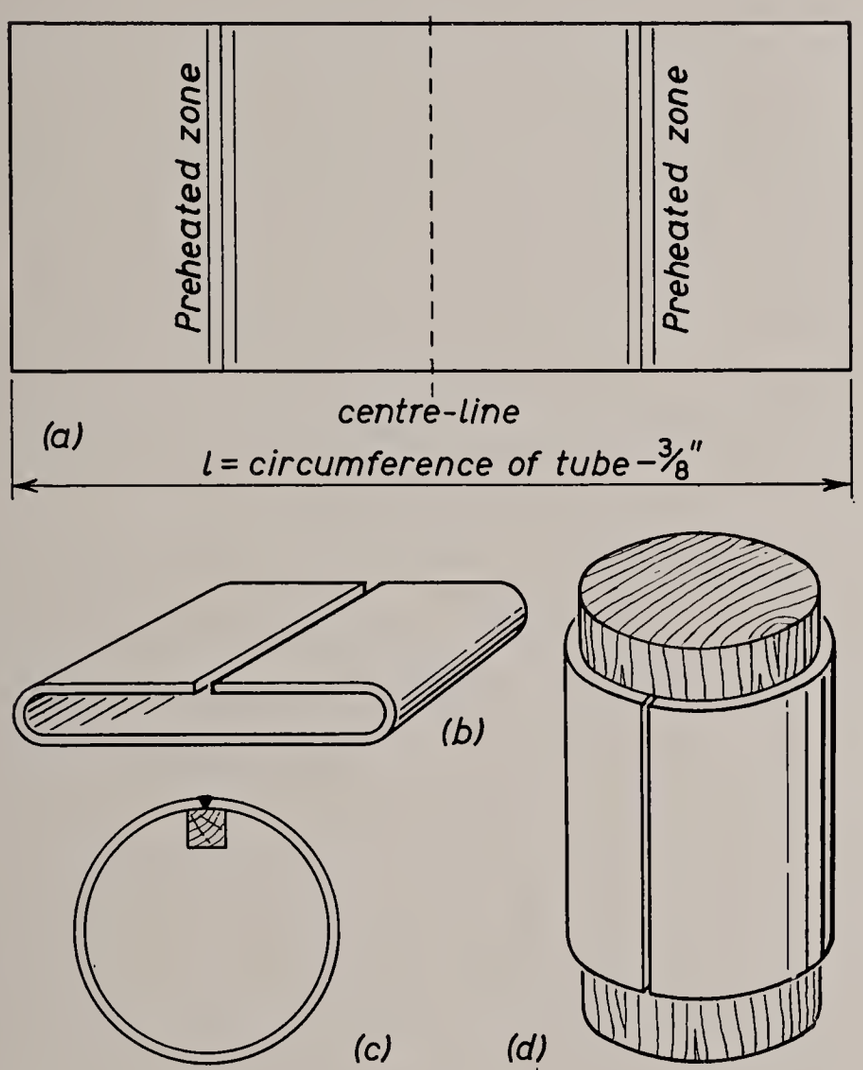


Fig. XV/1.—Making a large bore tube from rigid P.V.C. sheet.
(a) Marking of the sheet and preheating.
(b) Formation of a sleeve.
(c) Forming of a tube using a wooden mould.
(d) Welding of the tube.

$\frac{3}{32}$ in. filler rod to hold the sheet together during the preheating and forming operation. The sleeve so prepared is then transferred to a preheating oven and held there at a controlled temperature of approximately 265° F. (130° C.) for about 5–10 minutes. (The time required for softening the sleeve depends on the thickness of the sheet. At this temperature a sheet of $\frac{1}{16}$ in. thickness is suitably softened in 2 minutes,

$\frac{1}{8}$ in. sheets require 4 minutes, $\frac{1}{4}$ in. thick sheets 8 minutes, $\frac{3}{8}$ in. sheets 12 minutes. Prolonged or excessive heating will result in blisters and burning of the material).

The sleeve is then removed from the oven and quickly drawn over an appropriate former, Fig. XV/1d where it is left to cool. Contraction will cause a longitudinal break in the weld—alternatively the weld has to be destroyed either by cutting it with shears or with a knife. The opened sleeve is now withdrawn from the former and put on a support (see Fig. XV/1c), the chamfered edges are cleaned up, all traces of the provisional weld are removed and the sleeve is then properly welded together.

Following this procedure truly circular tubes and pipes can be produced. Most fabricators use some short-cuts: they eliminate, for instance, the tack welding stage and close the sleeve formed in the initial stages (Fig. XIV/1b) with a permanent weld, then preheat and soften the sleeve and draw it afterwards over a split former, see Fig. XV/5. The wedge in the former is removed after cooling causing the mould to collapse; the tube can then be removed easily.

This procedure is permissible for tubes of small diameter (9 in. to 24 in.). Split moulds for tubes exceeding 27 in. in diameter are rather expensive, furthermore, the wedge can no longer be forced in or withdrawn with ease.

Production of tubes by rolling pre-plasticized (softened) sheet supported on Kraft paper, over a wooden mould (see Fig. XV/2) is permissible where accurate dimensions and shape are immaterial. Such tubes can be mass-produced on a simple jig shown in Fig. XV/3 (*3*).

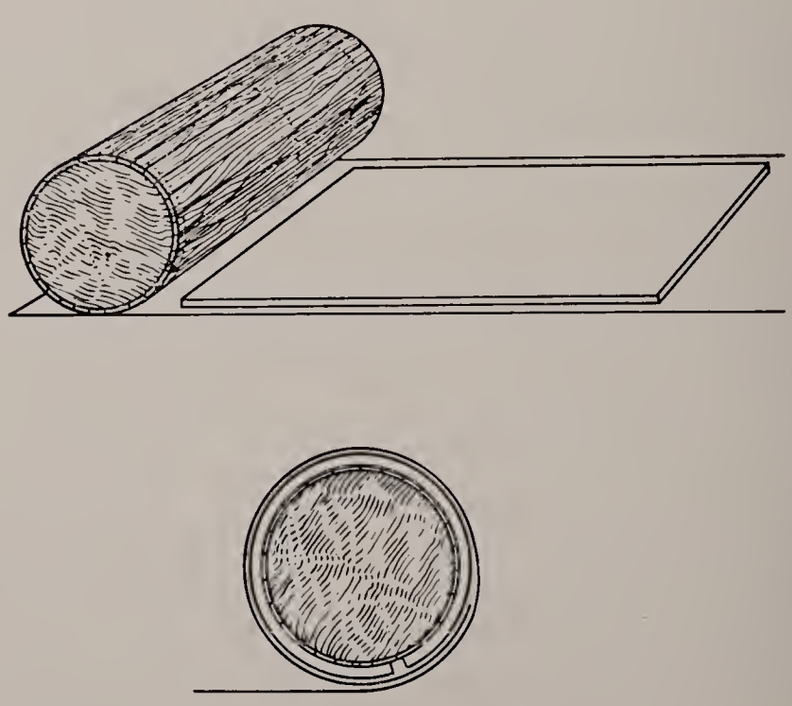


FIG. XV/2.—Forming of a P.V.C. tube by rolling it over a wooden mould.

Formers and moulds

The design and construction of the formers or moulds used for the production of P.V.C. tubes is of some importance. The tubes shrink to the surface of the mould on cooling and conform to the shape of the mould. All imperfections will thus be reproduced and any deviation from a truly circular shape in the mould will be found in the P.V.C. tubes.

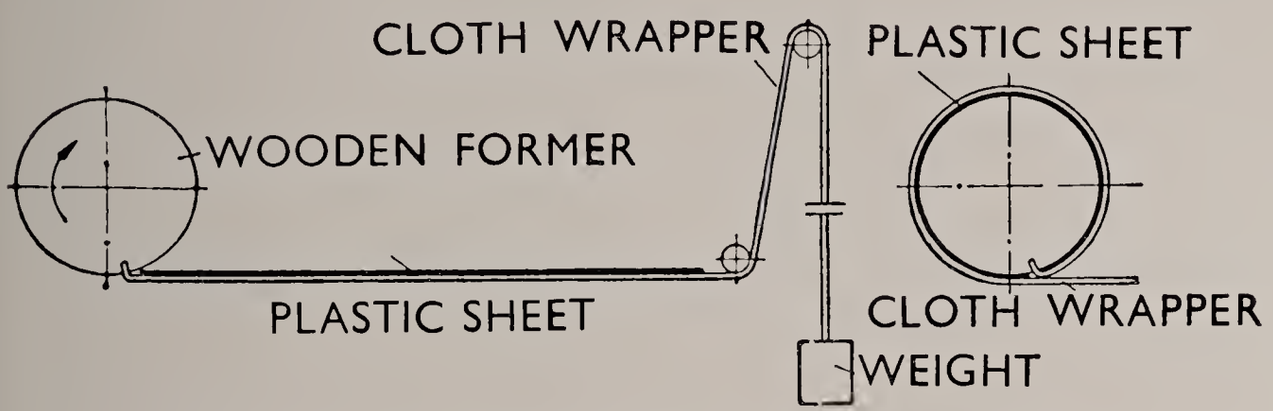


FIG. XV/3.—Jig for rolling tubes from preheated P.V.C. sheet.

Formers and moulds are usually hollow to save material and to reduce their weight.

FIG. XV/4.—Details of construction of a wooden mould for the fabrication for P.V.C. tubes.

Various methods are employed in their manufacture, depending on whether they are produced in the fabricator's own workshop or by an outside contractor.

A reasonably cheap method for their manufacture is the following.

Two or three wooden discs of an outside diameter slightly smaller than the inside diameter of the tube to be formed are drilled through the centre. A stick is then passed through these holes and the discs are then so arranged that a plywood sheet of $\frac{1}{16}$ in. to $\frac{1}{8}$ in. thickness can be wrapped around them. The plywood sheet is then nailed to the discs—i.e. a cylindrical mould is formed (Fig. XV/4).

An alternative to these moulds are split moulds or formers with a wedge in the centre, Fig. XV/5. The manufacture of these formers is, however, much more complicated and has to be undertaken by a carpenter or joiner.

The length of the tubes is limited and depends on the size of the P.V.C. sheets available. It can obviously not exceed the length of the sheet, but in general, and especially for large bore tubing, the height of the former corresponds to the width of the sheet, i.e. 3 ft. to 4 ft.

Transformation pieces require special formers which can be built from wooden frames (square) and rings of appropriate sizes which are held together under the desired slope or angle by means of wooden battens of $\frac{1}{2}$ in. width (Fig. XV/6).

Reducers can be formed on a simple, home-built device, consisting of a tripod and a spindle on which round discs corresponding to the diameters of the inlet and outlet of the reducer are screwed. Flat wooden battens of $\frac{1}{2}$ in. width are laid around these discs, forming a cone-shaped structure. The battens are held together with rubber bands. Fig. XV/7 gives details of this device. Changing the relative distance of these discs from each other obviously changes the slope of the cone.

FIG. XV/5.—Split moulds for making large bore P.V.C. tubing.

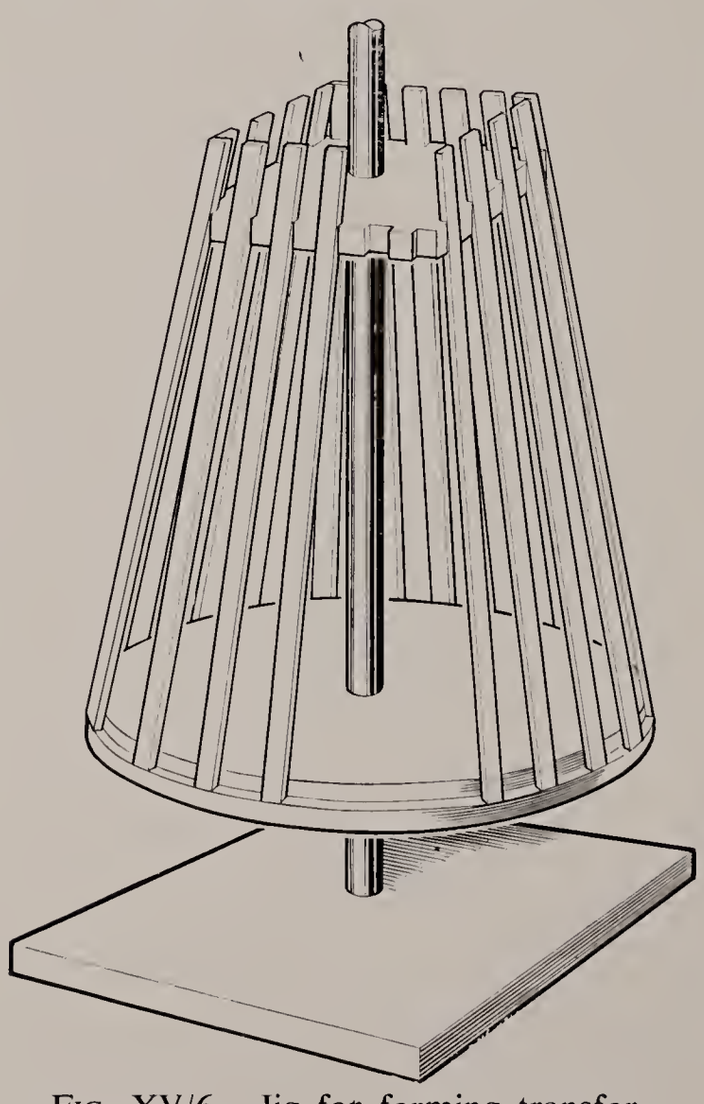


FIG. XV/6.—Jig for forming transformation pieces from rigid P.V.C. sheet.

Assembly of the tubes

The individual duct sections so produced vary in length from 3 ft. to 4 ft. according to the width of the sheet used for their fabrication. Three to six sections can be joined together by butt-welding; for extruded T-sections (see page 214), fillet-welds are employed.

It is essential to join the individual sections in such a way that the longitudinal welds do not continue right through, i.e. they are

staggered, to make sure that not more than two welds meet on any particular point (Fig. XV/8).

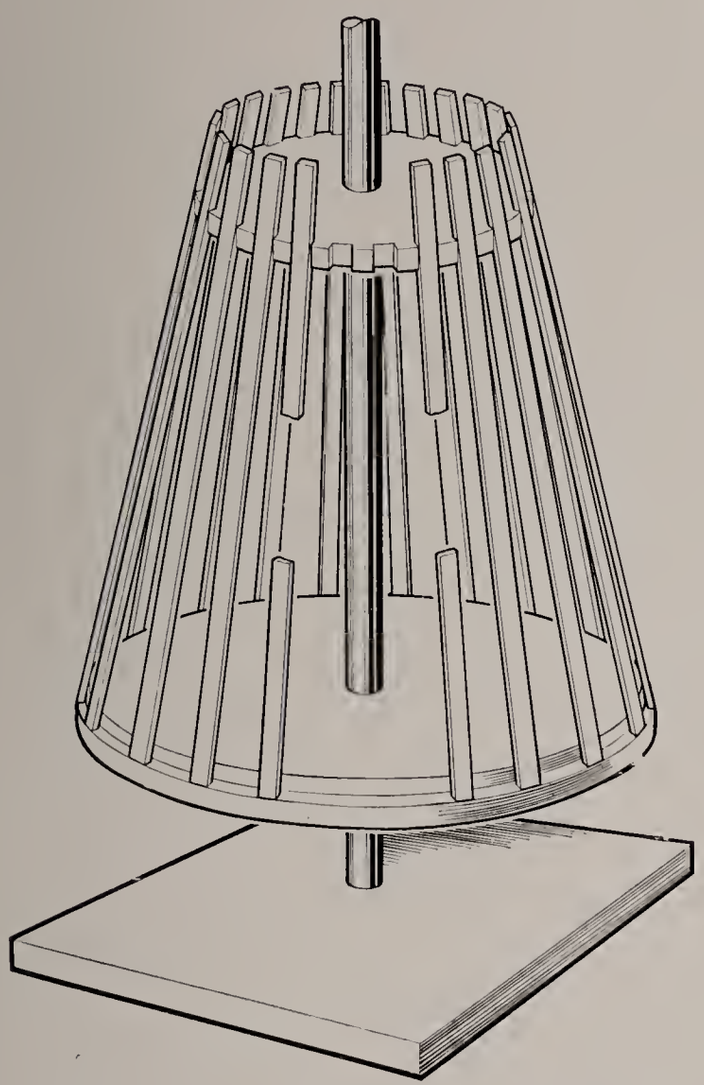


FIG. XV/7.—Jig for forming reduction pieces from rigid P.V.C. sheet.

Flanges

It is general practice to flange larger sections of a P.V.C. duct system to speed up assembly on site or dismantling in the case of repairs, etc.

There are also some other methods of connection in use for round ducts, for instance belling or sleeving; square ducts are, however, always assembled by means of flanges.

Round flanges can be cut (trepanned) from sheets of suitable thickness; flanges produced this way are rather expensive, especially in larger diameters as the inserts cannot always be used for smaller size flanges for the same job. These cut-out sections may accumulate in time and, as they have to be valued at a low figure for accounts purposes, greatly increase the price of the flanges used on a particular job.

An alternative and much cheaper method of producing round flanges for duct work is the following.

Flat strips of rigid P.V.C. (offcuts) up to 3 in. in width are cut to the required length, then softened in a preheating oven and laid around a wooden former (Fig. XV/9). The diameter of this former corresponds to the external diameter of the duct section to be flanged. The ring so formed is then closed by a butt-weld and left to cool; it is then withdrawn from the former, reheated and softened, drawn over the same former and quickly turned 90° (i.e. from the vertical position to the horizontal position). This is followed by flattening of the flange whilst

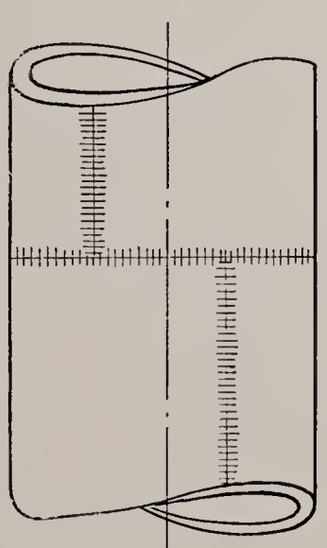


FIG. XV/8.—P.V.C. Duct section with staggered welds.

it is still soft by a wooden or metal disc. The flange is removed from the former after cooling and is them ready for use, unless trueing up on a lathe is required.

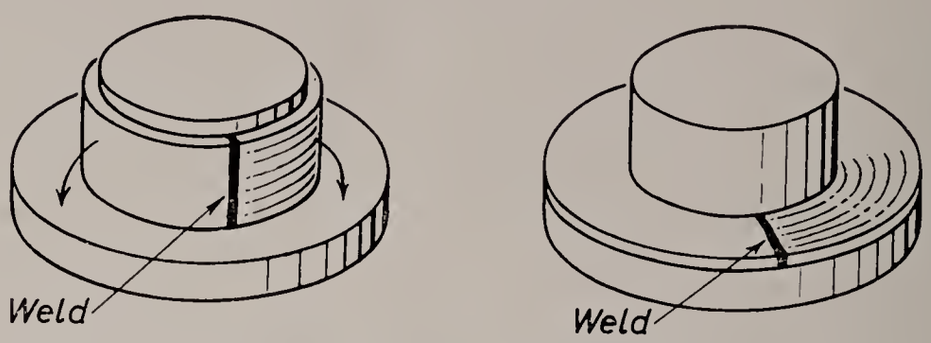
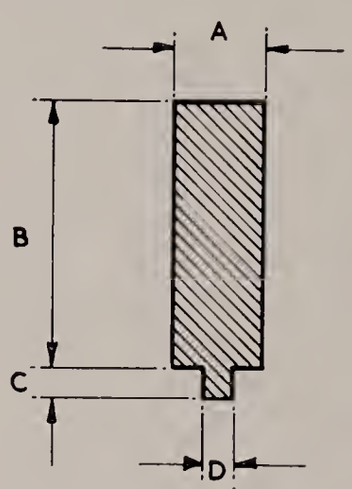


FIG. XV/9.—Fabrication of P.V.C. flanges from off-cuts.

The maximum thickness of P.V.C. strip that can be handled by this method is $\frac{3}{8}$ in. and this restricts the use of flanges so made to ductwork. Pipe flanges are usually cut from heavier sheet or moulded.

Flanging of individual sections in a duct system can be reduced to a considerable extent by using extruded T-sections (Fig. XV/10). Single,



A	B	C	D
10	25	25	5
10	50	25	5
10	70	25	5

FIG. XV/10.—P.V.C. T-section for duct work.

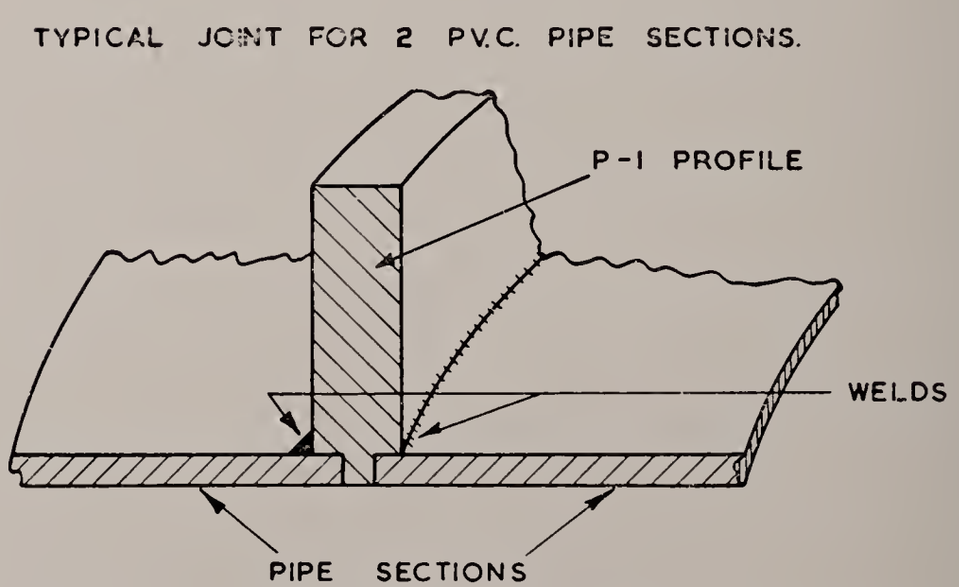


FIG. XV/11.—Application of P.V.C. T-sections for duct work.

circumferential fillet-welds secure the ends of the individual sections to the T-section which also acts as a stiffener (Fig. XV/11). Ordinary flanges are still required—but at wider intervals.

This method of jointing was developed by Somo, Switzerland, who manufacture and supply these extruded sections in three sizes in the form of helices with internal diameters varying from 16 in. to 50 in.

Fig. XV/12 shows a range of duct sections fabricated by means of these T-sections.

FIG. XV/12.—P.V.C. duct sections assembled by means of T-sections.

Square ducts

Square ducts are in general cheaper than round ducts: they can be produced more quickly and moulds are not required.

Preheating of the entire sheet and subsequent rolling, reheating and forming is avoided.

Material

Rigid, unplasticized sheets of $\frac{1}{16}$ in. to $\frac{1}{8}$ in. thickness are cut to size and the actual location of the corners is marked off. It should be noted that thinner material can be used for the fabrication of square ducts as the corners act as stiffeners.

Method of fabrication

The sheets, cut to size, are transferred to a bending machine and bent

to the required dimensions; the gap left is then closed by a longitudinal butt-weld; semi-automatic or automatic welding machines are ideally suited for this purpose. Extruded T-section can be used to reduce flanging to a minimum.

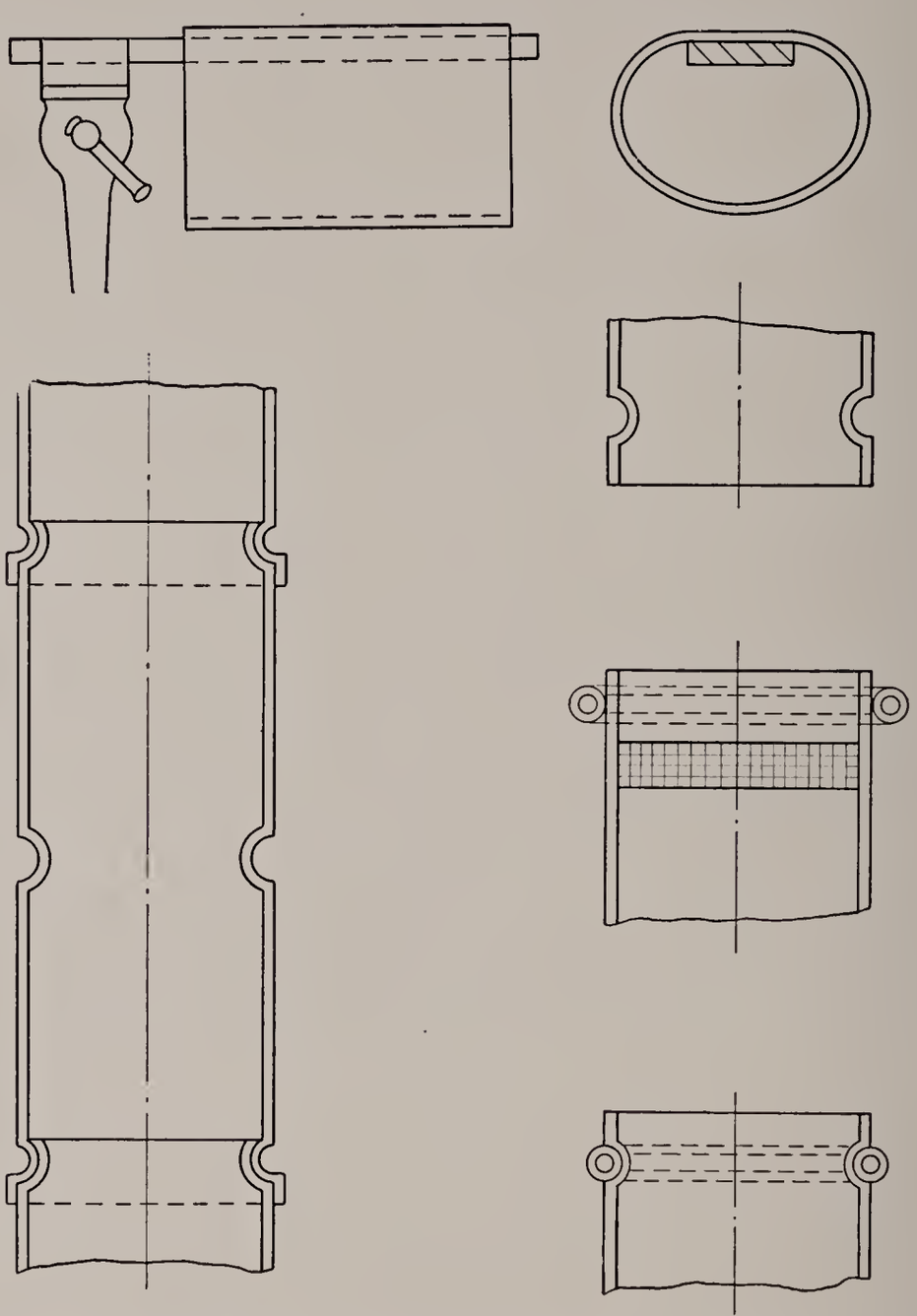


FIG. XV/13.—Fabrication of large bore tubes from rigid P.V.C. foil.

Flanges

Flanges for square ducts are fabricated from off-cuts.

Other methods of P.V.C. duct fabrication

There are quite a few methods of duct fabrication although those mentioned above are used in the majority of cases. All these alternative methods concern round ducts and they differ mainly in the method of jointing.

Cementing can be used, for instance, instead of flanging. A prefabricated rigid P.V.C. sleeve of suitable size is cemented over the abutting edges of two adjoining duct sections—alternatively a sleeve fabricated from plasticized P.V.C. sheet can be employed. The latter method is preferred in the case of long duct lines to provide for expansion and contraction.

Fabricated backs and T-pieces can be produced by preparing two half sections from P.V.C. sheet using suitable moulds and deep drawing. The two half sections are then welded together. A German firm uses specially grooved moulds for this purpose and the elbows or lobster backs so produced have, therefore, a pleated appearance. (The pleats act as stiffeners) (*4*).

A new method of fabricating duct lines from relatively thin unplasticized P.V.C. foil (1 mm. thick) was recently disclosed (*1*). Cylindrical sections are fabricated by welding, without the use of formers, and these sections are then provided with corrugations for stiffening and also to allow for sleeving, thus eliminating the use of flanges. This method was invented by Fossillet and is patented in France and other countries (F.P. 745,902).

Fig. XV/13 shows details of the method of fabrication and jointing of the individual sections.

Another method of manufacture of thin-wall tubing for duct lines developed by technicians of St. Gobain (*2*) is shown in Fig. XV/14. This method should be of particular interest to fabricators who do not possess a preheating oven or moulds of suitable size. Rigid P.V.C. foils of not more than 0·020 in. to 0·030 in. thickness are used; these are welded together and rolled as shown in Fig. XV/14a, care being taken to stagger the longitudinal welds. Further foils are then brushed over with a suitable cement and stuck over the first cylinder in such a way that the welds are well covered, see Fig. XV/14b. For exceptionally large tubes a third layer of foils may be applied. The extreme ends of the tube are then welded together by a butt-weld to prevent delamination. This method of tube manufacture is reasonably cheap due to a saving of time derived from the elimination of the preheating stage.

Installation

There are no standard rules for the installation of P.V.C. duct lines and one does not necessarily have to follow the methods used for metal ducts.

Steel or plywood backing rings are used to keep the flanges straight; reasonably soft packings are also required—these are cut from plasticized P.V.C., Neoprene, Hypalon or rubber.

The supports for rigid P.V.C. ducts need special consideration; they are not as rigid as metal ducts and some kind of support has to be provided at short intervals, in general every 3 to 4 ft. Flanging by means

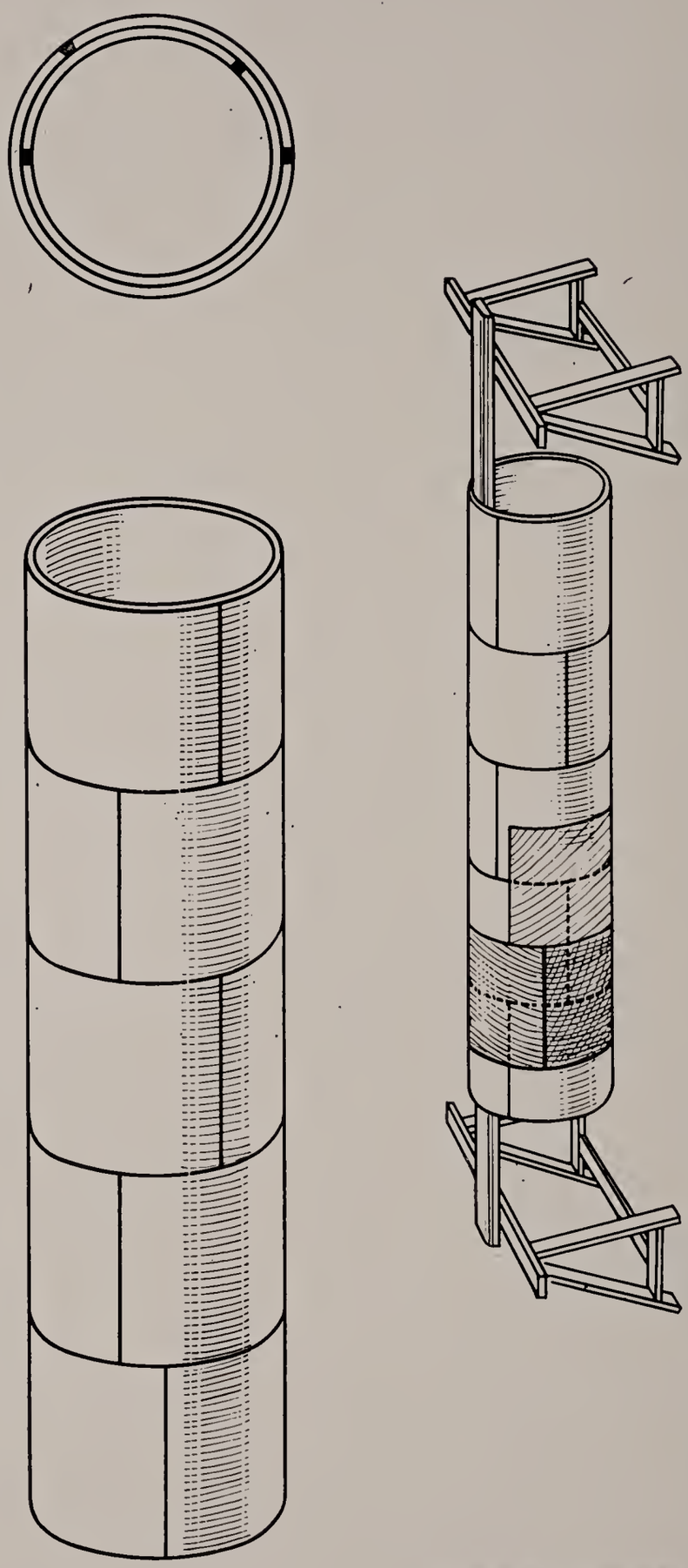


FIG. XV/14.—Schematic diagram showing details of a process for the manufacture of tubes from rigid P.V.C. foil by cementing and welding.

of saddles can be avoided if the flanges are drilled and hooks are used as shown in Fig. XV/15.

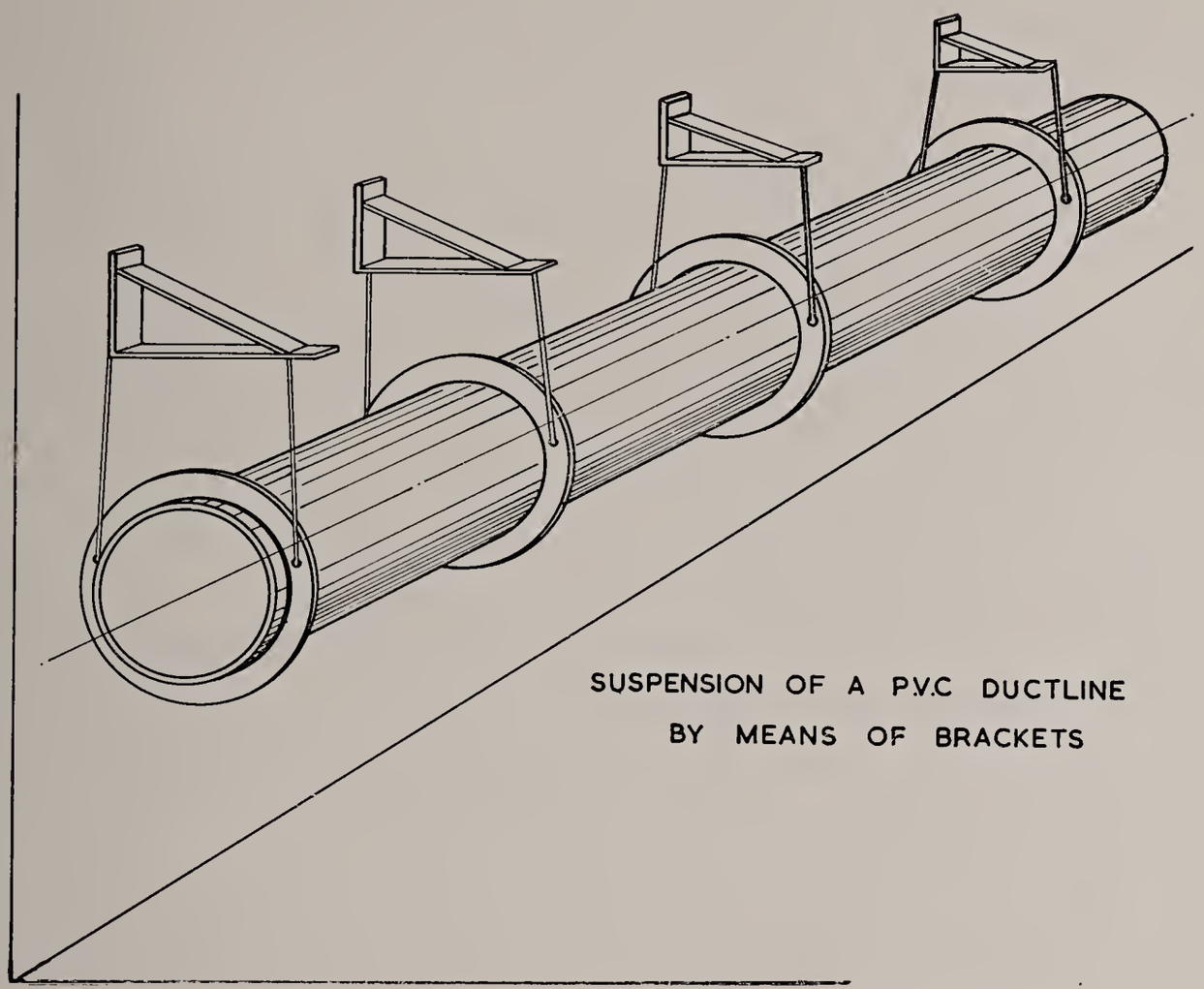


FIG. XV/15.—Method of supporting P.V.C. duct sections.

Great care should be taken to study the layout of the entire plant, its working conditions and the temperature peaks in a building before installing a P.V.C. duct system.

Radiation from hot water pipes or steam pipes passing underneath a P.V.C. duct may soften the duct and cause it to collapse. It should also be remembered that the temperature in a building changes with the height and is frequently 10–20° higher at roof level than on the ground floor. Figs. XV/16, XV/17 and XV/18 show a few typical duct installations in rigid P.V.C.

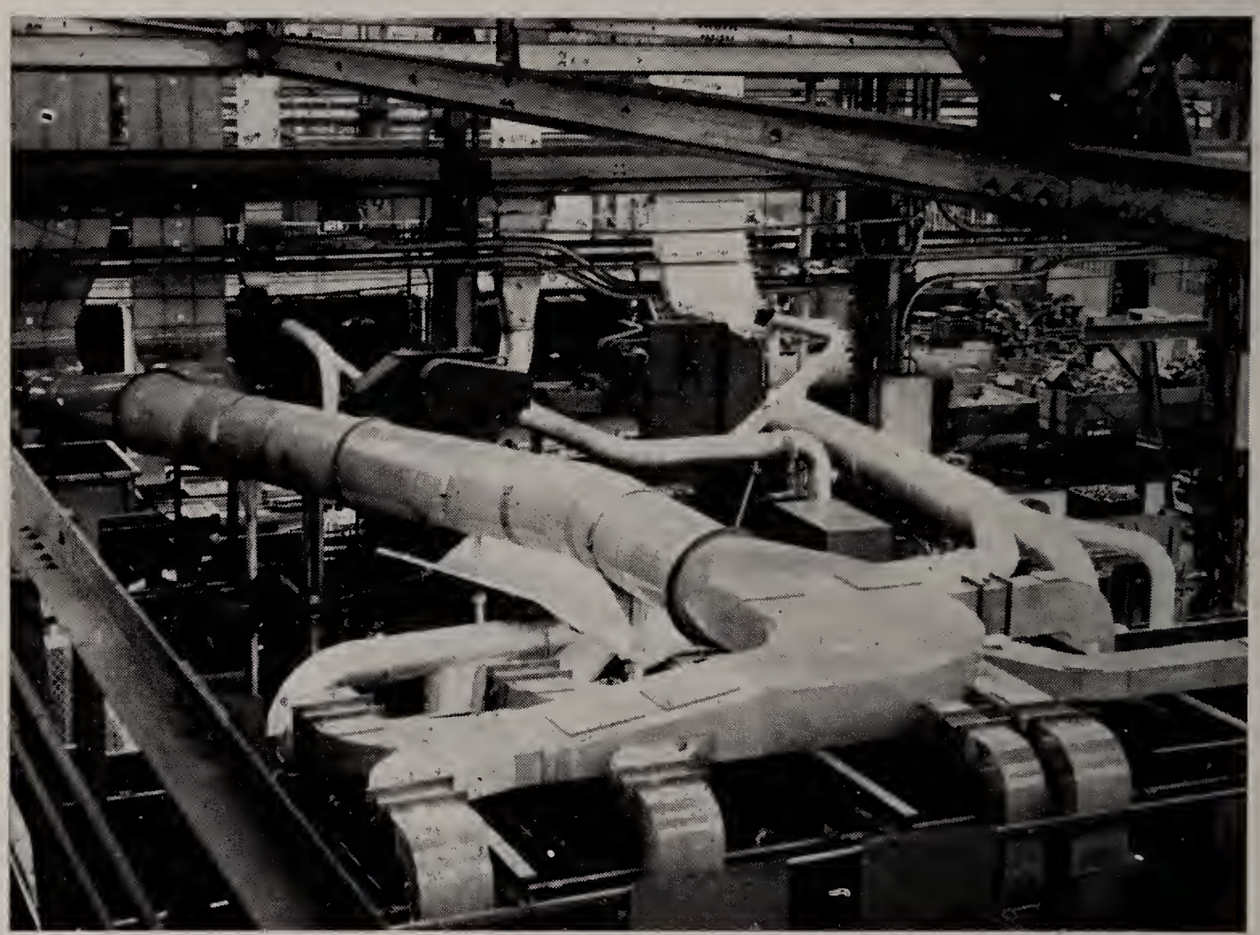


FIG. XV/16.—Large P.V.C. exhaust ducting for the extraction of fumes from a metal pickling plant.

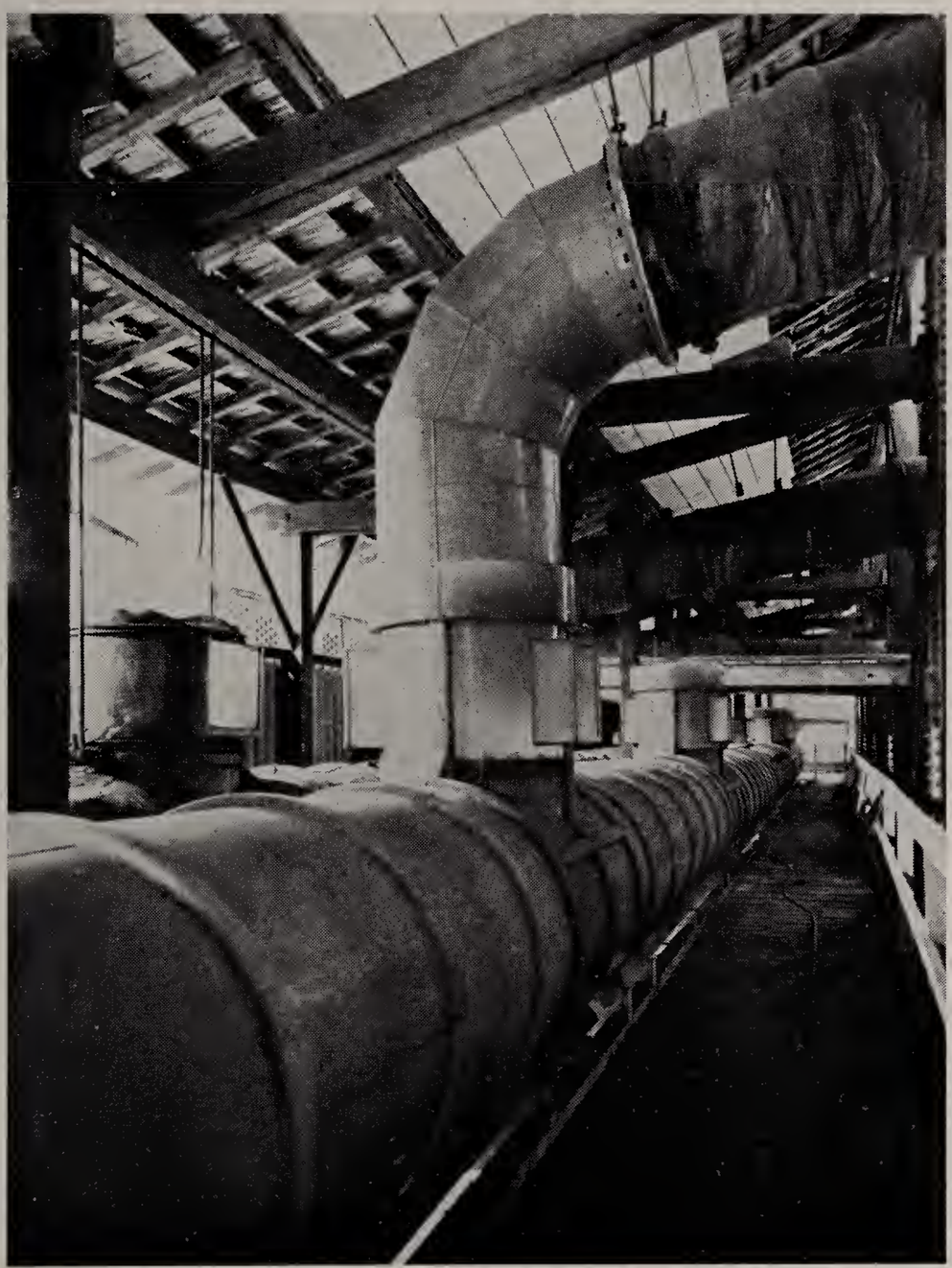


FIG. XV/17.—P.V.C. duct line in a sulphuric acid factory, 40 in. diameter, 125 ft. long.

FIG. XV/18.—Rigid P.V.C. De-airing device in sulphuric acid factory.

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CHAPTER XVI

POLYVINYL CHLORIDE IN THE BUILDING INDUSTRY

THE BUILDING Industry offers a wide range of applications of polyvinyl chloride of both the plasticized and the rigid (unplasticized) type. New uses and applications are found almost daily.

FIG. XVI/1.—Steel staircase with P.V.C. hand-rails.

Some of the more interesting applications such as hand-rails, floorings, gutters and rainpipes, roofings and expansion joints for large building operations will be discussed in detail.

P.V.C. Hand-rails

Until quite recently hand-rails for staircases were almost exclusively manufactured from hardwood, which requires a fair amount of initial polishing and maintenance at regular intervals.

Extruded profiles in slightly plasticized P.V.C. in pleasant colours are now finding their way into modern buildings, such as office blocks and apartment houses. A typical staircase installation with P.V.C. hand-rails is shown in Fig. XVI/1.

Their installation is simple and requires very little in the way of tools.

Details of the method of installation are given below.

Materials required

Extruded hand-rail profiles in rolls up to 60 feet in length, available in at least three sizes (Fig. XVI/2) and a wide range of colours.

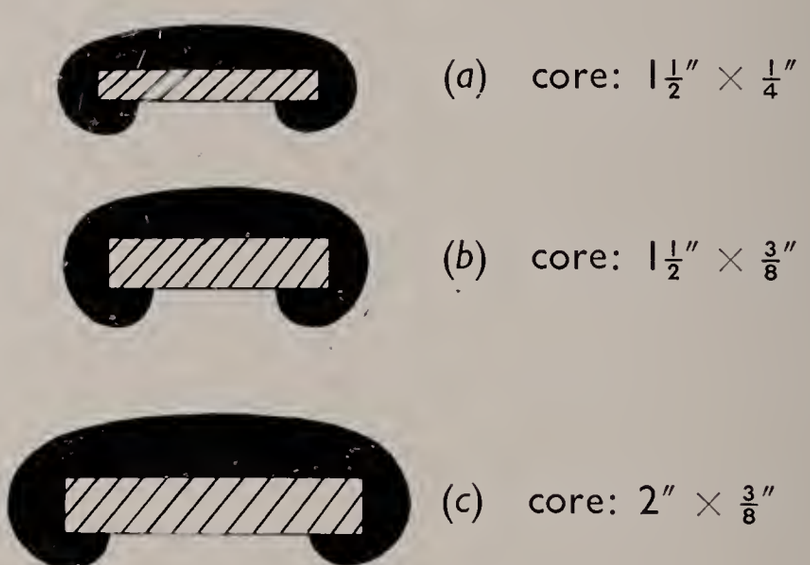

Fig. XVI/2.—Typical cross sections of P.V.C. hand-rails.

Equipment required

Cutting knives.
Files.
Special welding tool (heated tool type).
Preheating tool, Fig. XVI/3.

Method of application

The individual sections are cut to size and are then butt-welded together as shown in Fig. XVI/4. Care should be taken to avoid

charring and burning of the material. Any excess molten material will exude under pressure. This exûded material can then be trimmed off neatly and polished.

FIG. XVI/3.—Pre-heating of P.V.C. hand-rail with infra-red hand tool.

The individual hand-rail section is then to be passed through a preheating tool for softening and straightening. Once the material is soft and pliable it can be pushed over the steel rail to which it will fit properly after cooling and contracting. It is sometimes preferred to join the individual sections after they have been laid using the same type of heated knife; this alternative method requires greater skill and accuracy than the method outlined before.

The advantages claimed for this type of railing are the following:—

Cheapness. (P.V.C. hand-rails are cheaper than wooden ones);

Simple installation by relatively unskilled workmen;

Better resistance against wear and tear.

The fact that maintenance is not required makes these P.V.C. hand-rails even more attractive.

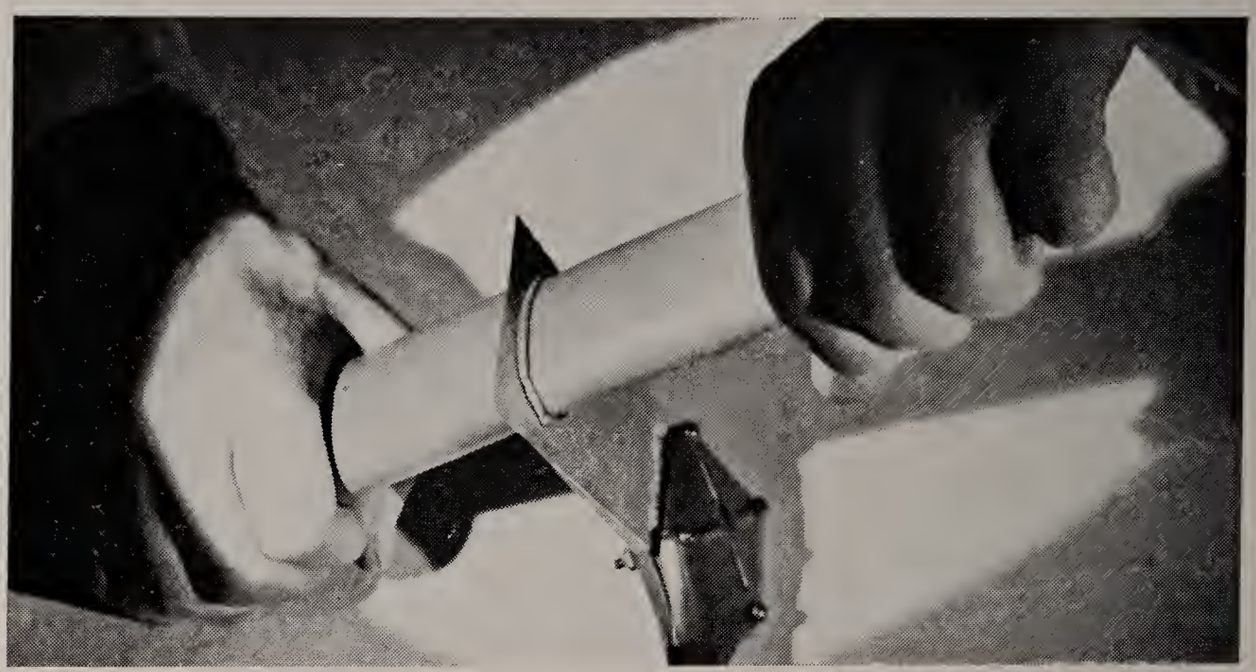

FIG. XVI/4.—Butt welding of two hand-rail sections using a heated knife.

PLASTIC FLOORINGS

A great variety of plastic floorings are available nowadays; the majority of these contain P.V.C. in one form or another (*3*).

The introduction of P.V.C. floor coverings goes back to 1937. In the earlier stages thicker material was used, nowadays thinner sheets of approximately $\frac{1}{8}$ in. thickness, or less, are employed. In general P.V.C. tiles or sheets are stuck to the floor, but for chemical factories and laboratories welded floors are preferred to prevent seepage of corrosive liquids through the gaps between the individual tiles or sheets.

Fig. XVI/5 shows a P.V.C. floor in a chemical laboratory; the joints were made by welding.

P.V.C. GUTTERING AND DOWNPIPES (RAINPIPES)

Practical considerations

P.V.C. gutters and rainpipes seem to be quite popular in the German Democratic Republic (D.D.R.); this rather interesting application has not yet made much headway in other parts of the world although numerous attempts have been made to introduce P.V.C. gutters and rainpipes in the United Kingdom and elsewhere.

Shortage of copper and galvanized iron were the main reasons why P.V.C. gutters were introduced around 1940 in Germany. The first installations were made on the roofs of some I.G. Farbenindustrie factories at Bitterfeld; later on metal gutters on the roofs of dwellings were replaced by P.V.C. gutters (*2*)

FIG. XVI/5.—Welded P.V.C. floor in a chemical laboratory.

They were fabricated from extruded, rigid P.V.C. tubing, cut in half; the individual sections were then sleeved at the ends and cemented together with P.C. cements. Some of the gutters installed in 1940 are still giving perfect service today.

The use of extruded tubing for this purpose was abandoned after 1945 for reasons of economy and also due to difficulties in obtaining larger bore P.V.C. tubes.

Today, gutters and rainpipes are heat-formed from P.V.C. foil of 0·040 in. thickness. The average plumber is not sufficiently experienced to carry out this work, neither has he the necessary equipment. He therefore buys standard P.V.C. gutters and rainpipes from firms specializing in this trade and assembles them on site after cutting by welding or cementing. Gutter bearers and brackets are used for fixing and supporting.

Approval tests (*4*)

Although P.V.C. gutters and rainpipes stand up better to corrosion than galvanized iron or copper guttering, doubts were raised whether the relatively thin material was sufficiently stout to withstand severe

winter conditions. Experiments carried out during the winter months of 1951/1952 proved that the thinner material stood up better than heavy wall guttering. Heavy icicles caused temporary deformation of the plastic foil from which the gutterings were made but the material snapped back to its original form after thawing without damage (*4*).

Further tests were started in the autumn of 1953 when an experimental gutter approximately 70 ft. long, fabricated from 0·040 in. thick foil, in 14 ft. sections, was installed on the roof of a hut on the Brocken in the Harz Mountains.

Extreme temperature changes with frost and considerable snowfalls are frequent in this region during the winter months.

No damage was reported up to the end of 1953 but early in 1954 heavy snowfalls caused the entire building to be buried in snow, the temperature fell to −11° F. (−25° C.) and wind velocities up to 12 (100 miles per hour) were measured.

The P.V.C. guttering was considerably less covered with rime and icicles than all the other materials such as metal, bricks and stones, which became heavily coated with rime and ice. The experimental installation was thoroughly examined in May, 1954, when four small holes were found in one of the gutters; it was assumed that these holes were made by ski sticks, since the entire building was snowed under and skiers had been over the roof; no other damage was reported. Further installations made in 1954 were still in a perfect state of repair by the end of 1956.

Installation of gutters (*4*)

The installation of P.V.C. gutters and rainpipes in the D.D.R. can only be undertaken by workmen holding a proficiency certificate in this technique (see page 296). There are also some D.D.R. government specifications governing the supply of the material. These specifications, issued in January, 1956, laid down the dimensions and weights, see Tables XIV and XV as well as the approved techniques for their installation. So far four sizes have been approved. Welding with P.V.C. strips (instead of filler rods) or cementing can be employed for their final assembly. An overlap of 2 in. approximately at the joints is recommended. Cemented joints should remain under pressure for approximately six hours to give the cement sufficient time to set properly.

Roofs on buildings are exposed to considerable changes in temperature and the same applies to guttering. The temperature in Eastern Germany, for instance, may vary from 105° F. (40° C.) in summer to −4° F. (−20° C.) in winter, and may be even lower in exceptional cases. The installation of P.V.C. gutters and rainpipes should therefore be undertaken during the seasons when the temperatures are not at extremes—in the spring or in the autumn, so that the expansion to

be expected in hot, summer weather, equals contraction in winter.

The rainwater heads of the guttering should be taken as fixed points and the gutters should be led into them in such a way that expansion and contraction can take place (the gutters must be able to slide); welding or cementing of the guttering to the rainwater heads is therefore ruled out.

In cases where these rainwater heads are installed more than 50 ft. apart special expansion joints should be inserted. Supports (gutter brackets) should be provided at intervals of 2 to 3 feet; continuous support by wooden boards is a suitable alternative. On no account should the supports be fixed in a way to hinder the movement of the guttering when expanding or contracting.

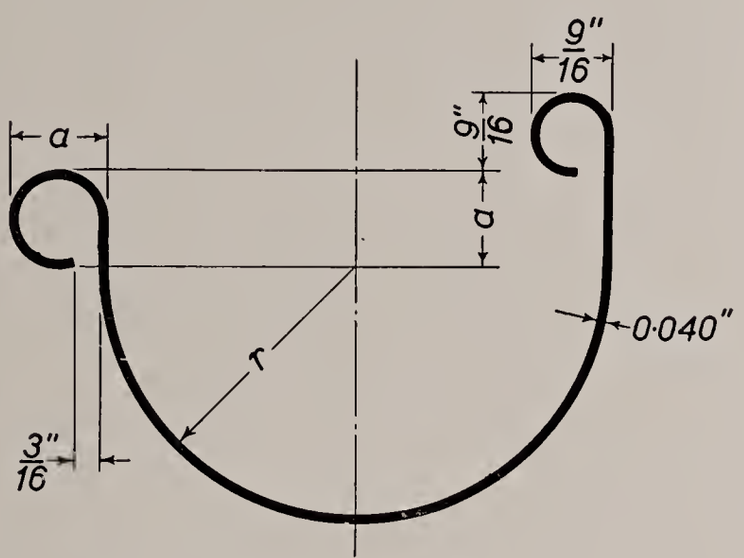

TABLE XIV
DETAILS OF P.V.C. GUTTERS

Nom. Size (2r)		$a \pm 0{\cdot}060$ *in.*		$r \pm 0{\cdot}080$ *in.*		*Weight*	
mm.	*in.*	*mm.*	*in.*	*mm.*	*in.*	*kgs./m.*	*lbs./ft.*
100	3·94	16	0·62	50	1·97	0·345	0·23
110	4·32	16	0·62	55	2·17	0·393	0·26
130	5·11	22	0·87	65	2·56	0·460	0·33
170	6·68	22	0·87	85	3·35	0·552	0·36

Supplied in 10 ft. lengths (3 m.).

Rainwater heads

The design of the P.V.C. rainwater heads may contribute considerably to the success or failure of the gutter installation. Practical experience has shown that tall and narrow heads are less liable to damage on thawing than heads of relatively large diameters.

Rainpipes

Rainpipes should be supported at regular intervals (7 feet or less). They should be kept at least 1 in. away from the walls of the building —the welded seams facing away from the building. Connection between the individual sections should be made by sleeving allowing for an overlap of at least 3 in. Welding or cementing of the joints is not permitted. The final section of the rainpipe (the last 4 feet or so) should be in cast iron, asbestos or concrete, as these are less liable to damage than rigid P.V.C. when accidentally knocked.

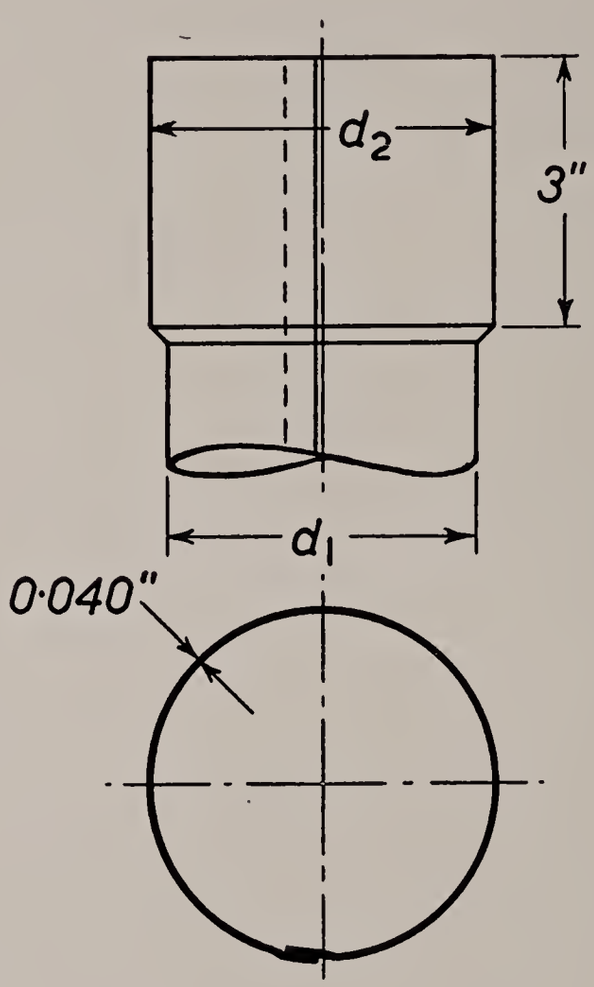

TABLE XV

DETAILS OF P.V.C. RAINPIPES

Nom. Size		$d_1 \pm 0{\cdot}040$ *in.*		$d_2 \pm 0{\cdot}040$ *in.*		*Weight*	
mm.	*in.*	*mm.*	*in.*	*mm.*	*in.*	*kgs./m.*	*lbs./ft.*
76	2·99	76	2·99	81	3·19	0·345	0·23
87	3·43	87	3·43	92	3·58	0·393	0·26
100	3·94	100	3·94	105	4·14	0·460	0·33
120	4·73	120	4·73	125	4·92	0·552	0·36

Supplied in $6\frac{1}{2}$ ft. lengths (2 m.).

Repairs

The repair of damaged P.V.C. gutters and rainpipes can be carried out by cementing a piece of P.V.C. of suitable size over the damaged area.

P.V.C. Roofing (*4*)

In the Eastern part of Germany (D.D.R.) rigid, unplasticized and plasticized P.V.C. foil and sheets are used as a roofing material.

Cornices, parapets and channels covered with P.V.C. are typical applications in this line.

The considerable coefficient of expansion of the material (8×10^{-5}) rules out any permanent connection of the P.V.C. cover to the supporting brickwork, concrete, wood and the like.

Temperature changes from 120° F. (50° C.) in summer to −40° F. (−40° C.) in winter can warp and destroy a plastic roof, unless precautions are taken to allow for expansion and contraction. These dimensional changes are much more pronounced on roofs with relatively large surface areas than on gutterings.

A reasonably large roof of approximately 4,500 sq. ft. on a hotel was covered with unplasticized P.V.C. foil for testing purposes, and in 1955 a smaller roof of approximately 800 sq. ft. was installed over the annex of a hotel in the Harz mountains. Both roofs were covered with unplasticized P.V.C. foil of 0·040 in. thickness. Special clips formed from rigid P.V.C. sheet 0·060 in. thick were nailed at regular intervals to the wooden roof in such a way that the individual sections of the P.V.C. roof could be fixed to them, leaving them to move freely in the vertical direction (i.e. up or down) although they could not be lifted off the roof by heavy storms. The individual sections were not jointed together; an overlap of approximately 2 in. was allowed on each section.

Other methods of fixing were also tried out with varying success. A final assessment of the merits of P.V.C. roofs has so far not been made.

Practical details

Preparation of surfaces to be covered. All surfaces to be covered should be smooth and free from ridges as these would hinder the movement of the P.V.C. roof when it expands or contracts.

In cases where a smooth surface cannot be provided, a layer of roofing felt should be interposed.

In general, relatively narrow surfaces only will have to be covered, although their length may be considerable. Typical examples are cornices and parapets. Expansion and contraction in the vertical direction is negligible under these circumstances but allowance has to

be made for horizontal movement. Considering extreme weather conditions one has to allow for an expansion or contraction of approximately 3 in. for every 10 yards of P.V.C. covering. Double welt expansion joints, such as shown in Fig. XVI/6 should be provided at 15 to 20 ft. intervals. Alternatively, extruded expansion pieces made from plasticized P.V.C., Fig. XVI/7, can be employed.

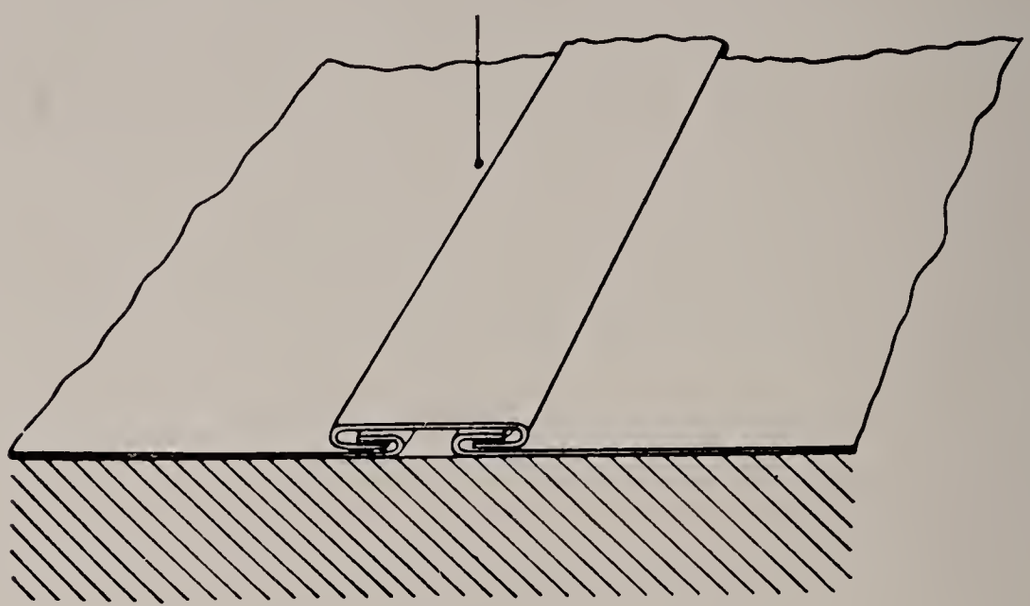

FIG. XVI/6.—Double welt expansion joint for P.V.C. roof cover.

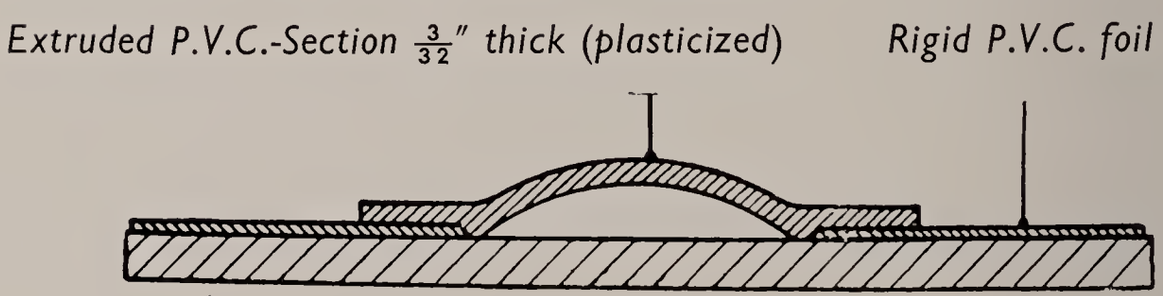

FIG. XVI/7.—Extruded expansion piece in plasticized P.V.C. used on P.V.C. roof coverings.

The frontal edges of the covers for cornices should be firmly fixed to the roof to prevent lifting of the covers in cases of heavy winds. Methods of fixing are shown in Figs. XVI/8 and XVI/9. The connection of P.V.C. roofing materials to walls and brickwork has not yet been solved satisfactorily. Cover flashings, Fig. XVI/10, made from 0·060 in. thick P.V.C. sheet can be employed for instance.

A method for attaching a parapet cover in rigid P.V.C. is shown in Fig. XVI/11.

Roofs made from rigid unplasticized P.V.C. foil are laid in individual sections, each 25 in. to 40 in. wide, with an overlap of approximately 2 in. in vertical direction.

The direction of calendering of the rigid P.V.C. foil is of importance and foil employed for roofing should always be used in such a way that

the direction of expansion and contraction takes place at right angles to the direction of calendering.

The direction of calendering is, however, unimportant for roofings made from plasticized P.V.C. Lap-welding the joints by means of heated tools is almost exclusively used in this instance.

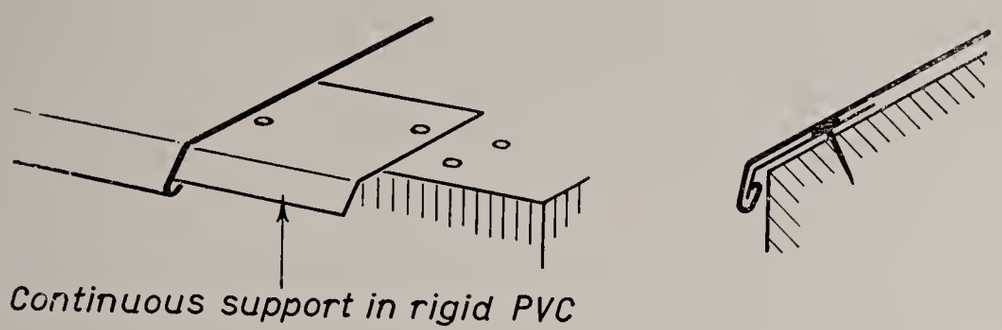

FIG. XVI/8.—Method of fixing P.V.C. roof coverings.

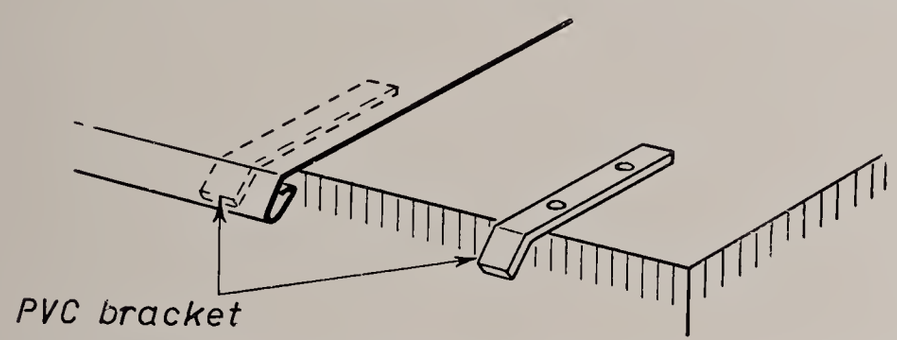

FIG. XVI/9.—Alternative method of fixing P.V.C. roof coverings.

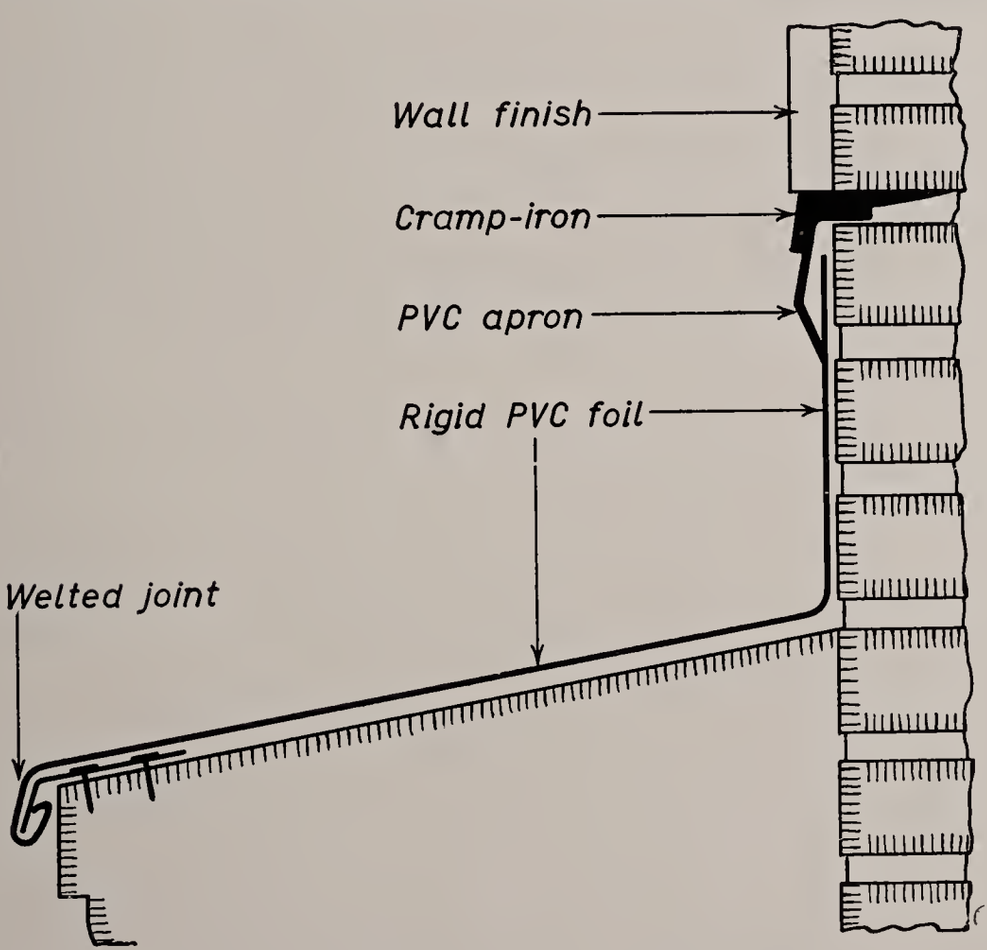

FIG. XVI/10.—Method of fixing a P.V.C. roof covering to a brick wall.

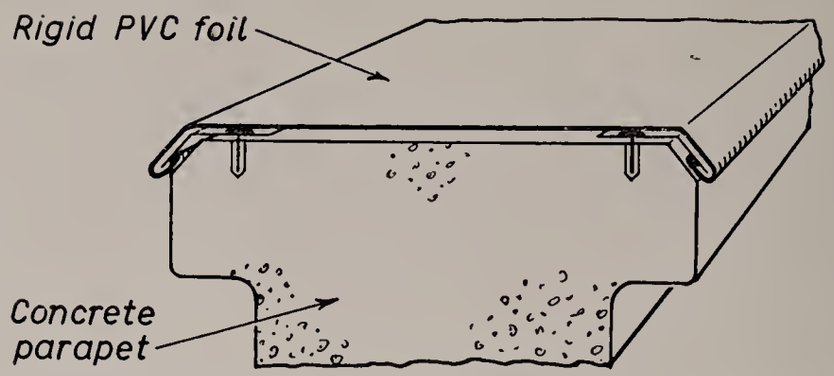

FIG. XVI/11.—Typical method of fixing a P.V.C. cover to a concrete parapet.

PLASTICIZED P.V.C. PROFILES ON STEEL SUPPORTS AS CONSTRUCTIONAL ELEMENTS FOR WINDOWS, DOORS AND PARTITIONS

A rather unusual but extremely useful application of plasticized P.V.C. has recently been reported from Germany where the Dynamit A.G. Troisdorf has developed a range of steel profiles covered with plasticized P.V.C. in co-operation with Hermann and Pasche, Hamburg. (*1*).

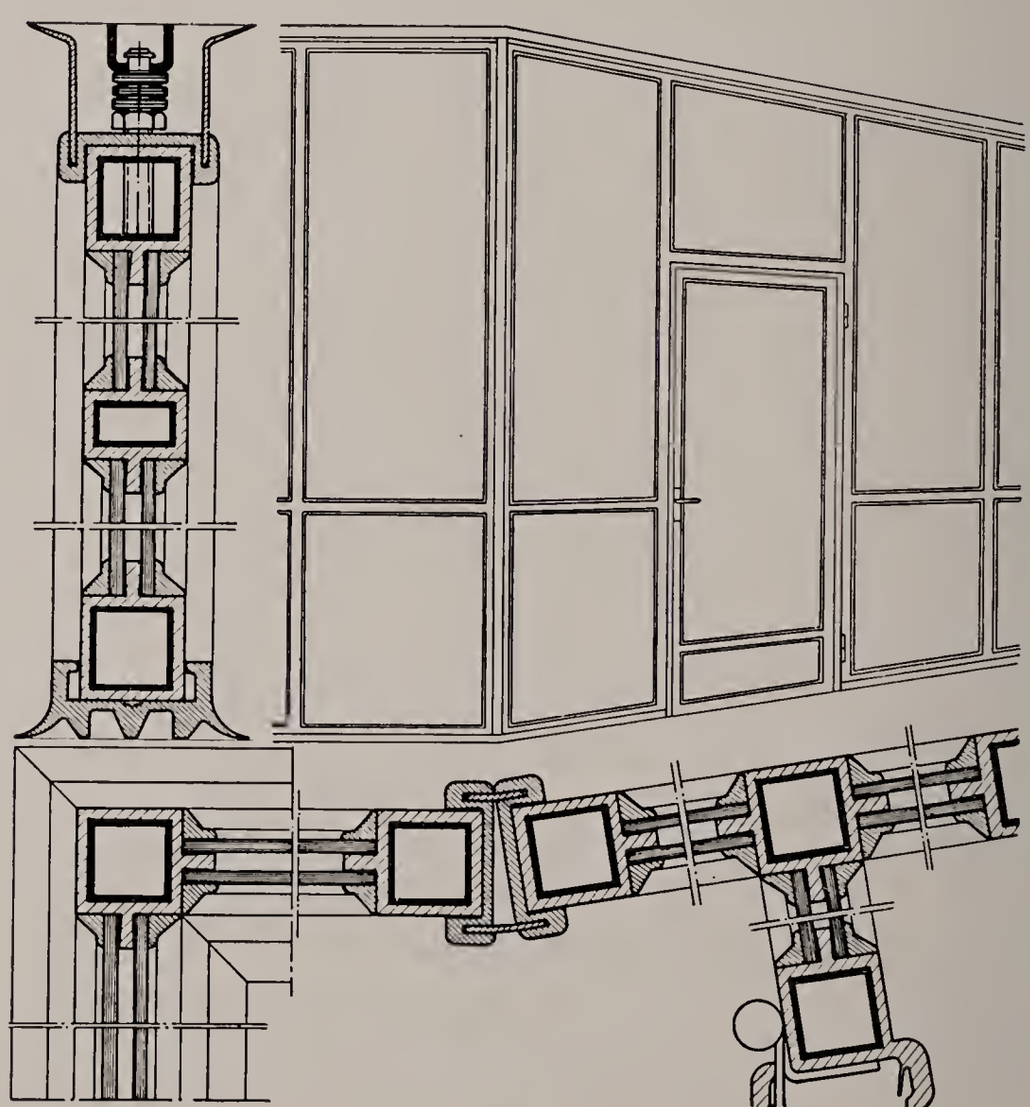

FIG. XVI/12.—Typical examples of steel profiles covered with plasticized P.V.C. used on office partitions.

These new construction units consist basically of a square steel section which is covered with a plasticized P.V.C. profile. A wide range of different profiles, including glazing and weathering bars, to facilitate the insertion of window panes is available; other sections have been produced for the erection of steel or plastic partitions in offices, apartment houses, etc. So far nine different profiles are available for the assembly of windows and window frames; for the assembly of partitions a few further supporting elements can be obtained.

These new construction units are of high mechanical strength and sound proof; further advantages claimed are excellent heat insulating properties and resistance against chemical attack (corrosion).

The P.V.C. compound used is non-inflammable and does not age appreciably. The smooth surface of the profiles prevents the settling of dust and bacteria. Jointing is effected by means of welding with either gas torches or especially constructed butt-welding machines.

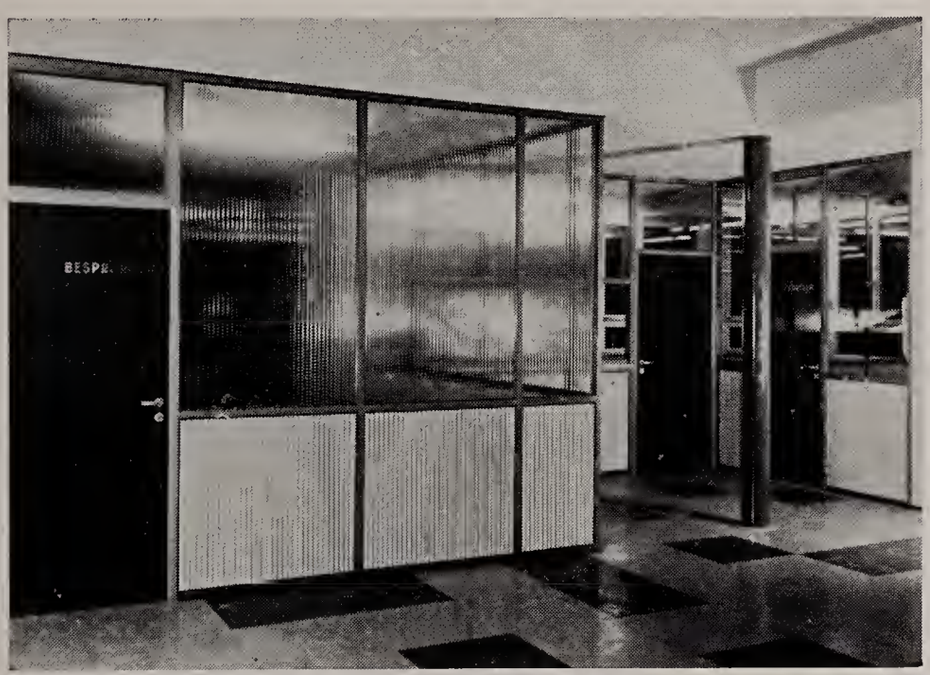

FIG. XVI/13.—Office partitions constructed of steel sections covered with plasticized P.V.C.

Installation

The standardized steel sections, made elsewhere, are covered with plasticized P.V.C. profiles by the Dynamit A.G.; they are available in lengths of approximately 20 ft. from licensed stockholders. Special instructions for their installation are issued. Fig. XVI/12, 13, and 14 show some typical profiles and some of the installations recently made.

Wall Coverings

Rigid P.V.C. panels with highly polished surfaces have been used

on a trial base as a wall covering in Laboratories, Hospitals, Schools, Canteens and Hotel kitchens. Individual panels measuring up to 2 ft. × 2 ft. are cemented to suitably rendered brick walls, plaster boards or wood using Neoprene or pressure sensitive cements. An alternative method of fixing is provided by a patented slotted P.V.C. extrusion with snap-on cover. The decorative panels are slipped into position and the cover pressed on.

The chief attraction of this type of wall covering is speed of installation, apart from low costs for material and labour.

FIG. XVI/14.—P.V.C. covered steel window frames and door frames in modern block of flats.

Plasticized P.V.C. strips for expansion joints

There is a tremendous scope for plasticized P.V.C. strips used for water-tight joints in the building industry. Bituminous materials—rubber—metallic covered strips, start out water-tight but in most cases they do not stay water-tight. Bitumen joints keep out the water for a short time but contractions, due to temperature changes, soon cause leaks. Rubber ages and perishes. Copper strips are too rigid to give satisfaction. Copper joints horizontally applied will not give when the

concrete underneath drops away with the result that cavities are left on the underside of the joint.

It seems that the solution to this old problem is plasticized P.V.C. strip of special section. This is made under the registered trade name of

FIG. XVI/15.—Cross section through Durajoint strip.

Durajoint and Duraseal by the Micanite and Insulators Company Limited, London. This type of strip is covered by British Patent No. 646,268. This strip has a specially designed ribbed cross-section which provides effective bonding to the concrete and gives maximum resistance

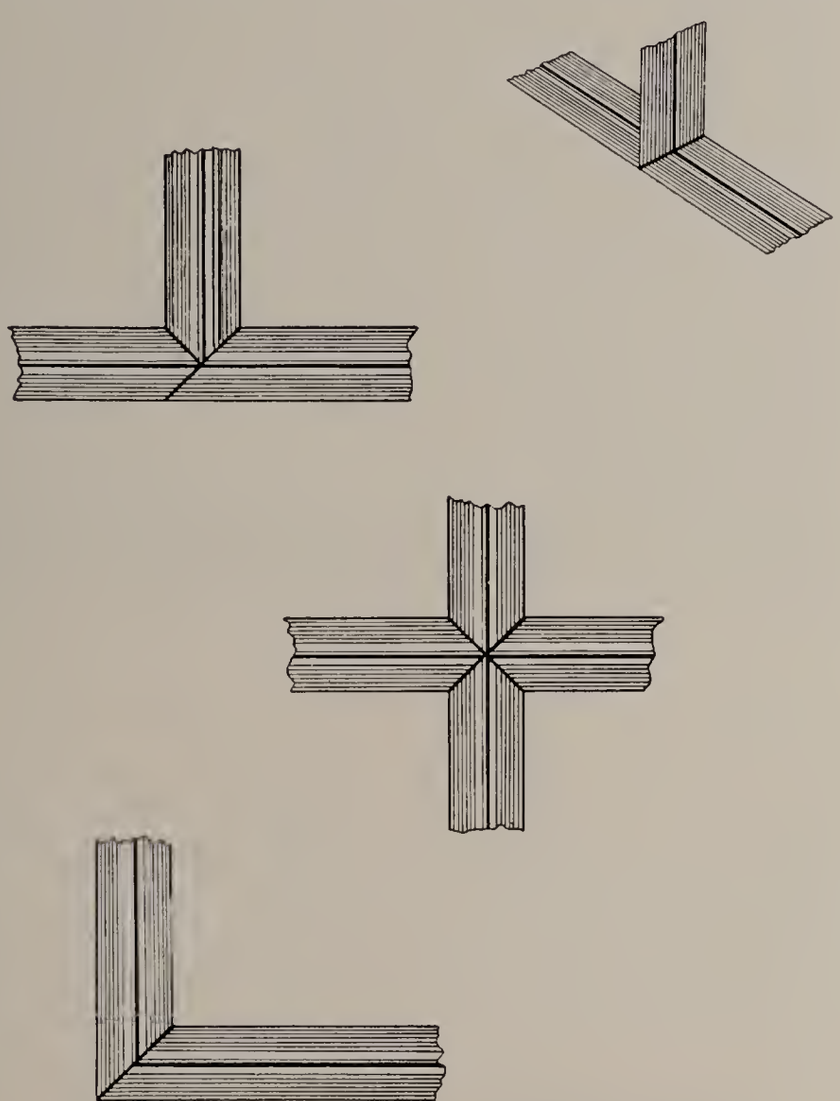

FIG. XVI/16.—Some typical welds in Durajoint.

to leakage for a given overall width of strip. The central tubular section ensures that stretch to accommodate relevant movement between adjacent sections of the concrete is restricted to the central

portions of the section, so that adhesion between concrete and strip is not disturbed. Under tests, 9 in. wide Durajoint strip withstood water pressure of 150 p.s.i. (10·5 kg./sq.cm.) corresponding to 350 ft. or 107 metres head. Sealing strips are not required although Durajoint is compatible with bituminous compounds. Durajoint retains its toughness, flexibility and tensile strength between wide temperature limits. Micanite and Insulators Ltd. provide this Durajoint also in an arctic grade.

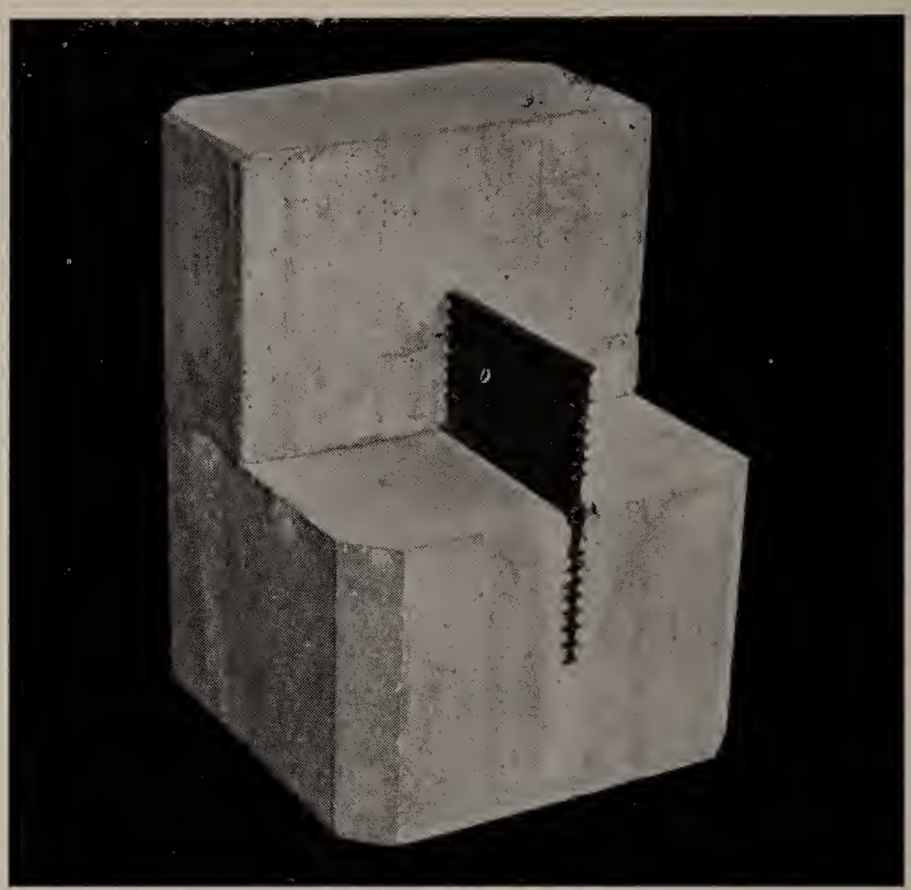

FIG. XVI/17.—Cut-away portion of concrete in which a Durajoint strip has been installed to form a flexible water-tight diaphragm.

A cross-section through Durajoint is shown in Fig. XVI/15. The material is supplied in rolls and it can be left exposed for long periods. The strips can be spliced quickly by the application of a hot steel knife and welding can be used in the pre-fabrication of special sections such as rings and the like for immediate applications. Alternatively,

FIG. XVI/18.—Duraseal strip.

joints can be made on site. Butt-welds, T-welds, cross welds and 'L' joints can be made simply using a hot knife. Alternatively, the material

can be grooved out and a weld made with triangular P.V.C. filler which gives far greater strength than knife welding. A variety of welds used in applications involving Durajoint are shown in Fig. XVI/16.

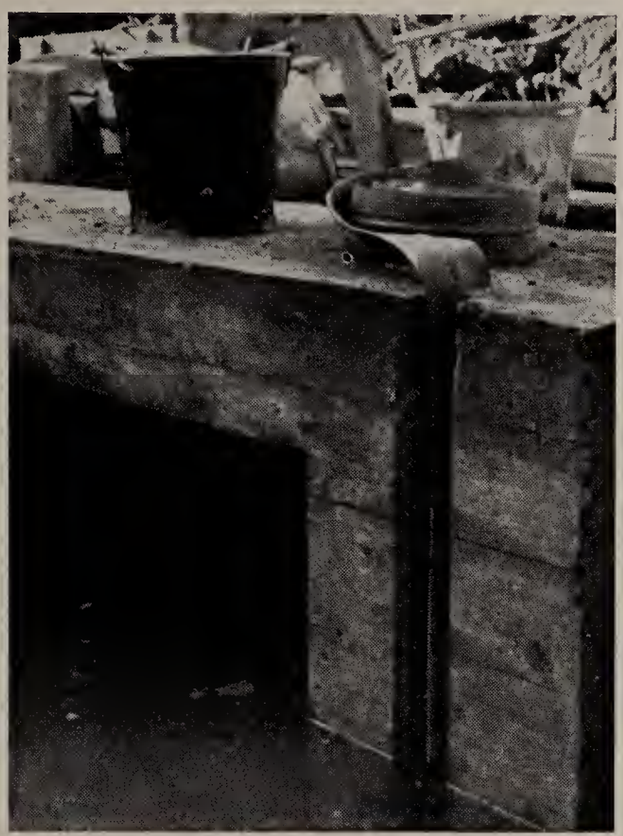

FIG. XVI/19.—Durajoint strip in the lower part of the wall of a small building.

The basic principle involving the application of Durajoint is that one half of the width of the strip is embedded in each side of the joint between adjacent sections of concrete. It is, therefore, necessary to protect one half of the strip from contact with concrete when the first section is cast. Fig. XVI/17 shows a cut-away portion of concrete in which Durajoint strip is installed to form a flexible water-tight diaphragm between the joint at the sections.

Duraseal, see Fig. XVI/18, is another type of plasticized P.V.C. strip made by the same company. Duraseal is covered by British Patents Nos. 646,268 and 775,558. Fig. XVI/19 shows a $3\frac{3}{4}$ in. Durajoint in the lower part of the wall of a small building. Fig. XVI/20 illustrates the use of Durajoint in the construction of the intake part of a weir for the diversion of the River Noe.

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CHAPTER XVII

APPLICATIONS OF POLYVINYL CHLORIDE IN INDUSTRY

THE CHEMICAL industry and its related branches are large users of rigid polyvinyl chloride. The excellent resistance of the material to a large variety of chemicals, good insulating properties and ease of fabrication are responsible for the wide scale acceptance of polyvinyl chloride as a new material of construction.

Originally a substitute for other materials of construction in short supply, polyvinyl chloride is today selected for specific applications where it gives better service than other materials previously used.

Other plastic materials such as polythene, polyisobutylene, polypropylene and a few other thermoplastic materials compete with polyvinyl chloride but they are not as popular nor as universally applicable.

The production of polyvinyl chloride the world over totals almost one million tons. It may, however, come as a surprise to many readers of this book that the total annual consumption of rigid P.V.C. in the chemical industry proper hardly amounts to 5,000 tons. There have been some misleading statements in trade journals alleging that the Germans use approximately 40,000 tons of rigid P.V.C. per year for chemical plant construction, but there is certainly no foundation for such statements, and German experts are not prepared to confirm that even 4,000 tons are used for this particular purpose in their country.

The examples quoted below are typical for the more important applications of P.V.C. in various branches of industry. An attempt has been made to present photographs not yet shown elsewhere. The building industry is not included in this survey as the use of P.V.C. in building has already been dealt with.

Commodities of general usefulness, such as fans, fume cupboards, pumps and valves, are discussed first as their use is not confined to any particular industry.

This is followed by a description of typical applications of P.V.C. in the chemical industry proper; applications in other industries are dealt with subsequently.

Fans and blowers

It is only natural to think of P.V.C. fans and blowers when making plans for the installation of a P.V.C. duct system. Until recently it has been the practice to use rubber-lined steel fans for such applications

but rubber does not stand up well to the action of strong acid fumes; it ages and becomes brittle when in contact with nitric acid fumes.

FIG. XVII/1.—Moulded P.V.C. blower of 800 cu. ft. per minute capacity.

Experience over the last 20 years indicates that P.V.C. fans and blowers last longer and give better service than rubber lined fans. Most fabricators of steel fans offer today P.V.C. fans of their own make and P.V.C. fabricators seek the co-operation of experienced fan manufacturers to help them with designs and advice. It is therefore not surprising that P.V.C. fans resemble in general customary types of steel fans. A wide range of types such as ordinary low pressure fans, turbo blowers, high pressure fans, etc., is offered in a variety of sizes and some makers offer more than 100 different models.

Smaller types with capacities up to 2,500 cu. ft./min. are moulded, Fig. XVII/1. The housing is deep drawn from sheet, whilst the rotor is injection moulded or fabricated.

Larger sizes are entirely fabricated; types with a capacity of up to 12,000 cu. ft./min. are produced for stock, larger fans with capacities up to 35,000 cu./ft. min. are only made against specific orders.

The design and fabrication of large fans requires great experience

and failures of fans in service are often due to the fact that they were too flimsily built (the rotor should be particularly robust to prevent fracture under impact).

Fig. XVII/2 shows one of the larger P.V.C. fans produced abroad. It has a capacity of 7,000 cu. ft./min. and is driven by a 15 H.P. motor at 1,000 r.p.m.

FIG. XVII/2.—Large P.V.C. Fan of 7,000 cu. ft. per minute capacity fabricated from P.V.C. sheet by welding. Static pressure 4 in. 15 h.p.

The rotor is usually the most expensive part of the fan, particularly in larger sizes. The blades have to be moulded by hand; they are subsequently welded to the disc of the rotor using jigs. Fig. XVII/3 shows a fabricated P.V.C. rotor of 5 ft. diameter.

All rotors should be properly balanced (statically and dynamically), and larger fan fabricators have balancing equipment on their premises to avoid delays caused by sending out rotors to firms who specialize in balancing. Balancing is achieved by adding on off-cuts of P.V.C. in the correct position. This is achieved by gluing on or by sticking on with plasticine; once the fan has been properly balanced the additional piece is welded on. On the other hand, an excess of material is removed by drilling holes in the correct position. The shaft bearing the motor should be covered with a P.V.C. sleeve (shrunk on) to prevent corrosion by gases passing through.

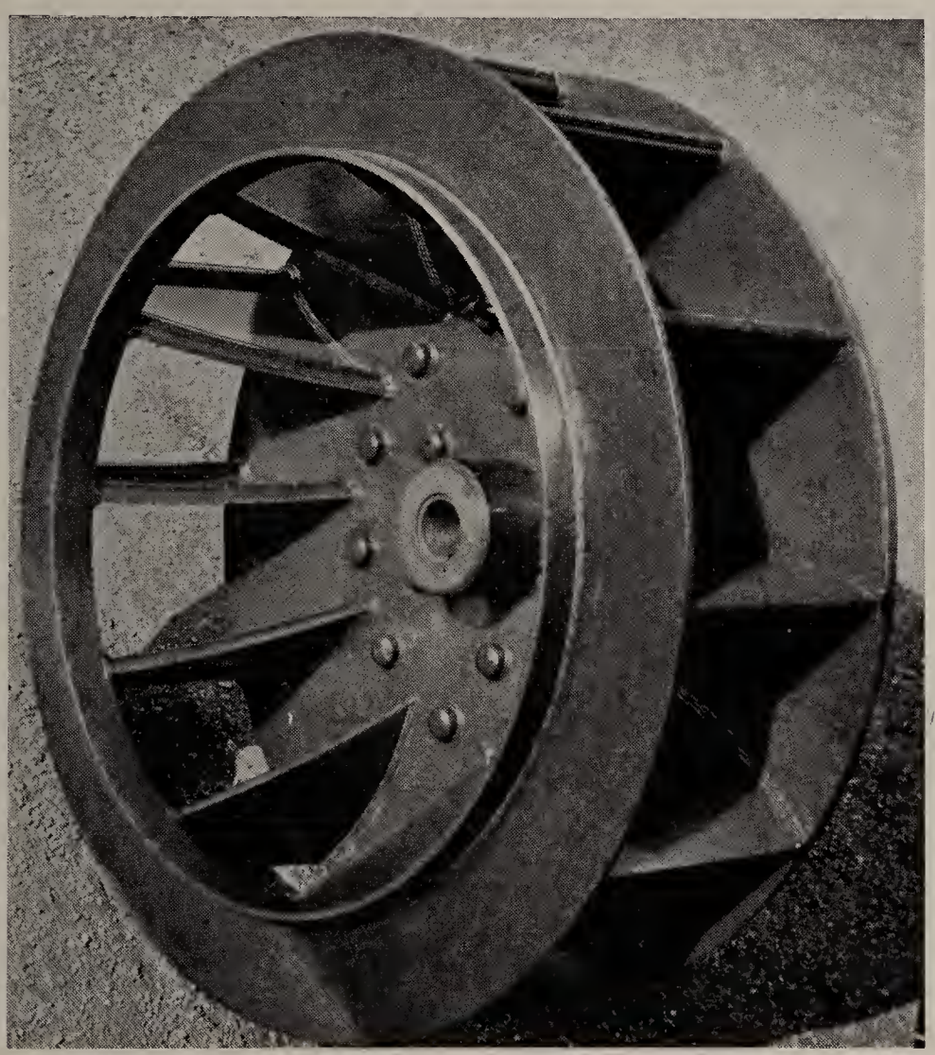

FIG. XVII/3.—Fabricated P.V.C. rotor 5 ft. diameter for P.V.C. blower.

Smaller fans are usually directly driven by motors with speeds up to 3,000 r.p.m. Larger fans are unsafe at such speeds and it is therefore preferred to drive them via pulleys and belts. This has the further advantage that the speed and also the output can be varied within reasonable limits. In some cases completely enclosed motors or flame-proof motors are specified by customers.

Attention should also be given to the screws, bolts and backing rings used; these are, in general, made of steel and have therefore to be

covered with corrosion resistant paint. The gaskets should be cut from plasticized P.V.C., neoprene or rubber.

Grilles should be provided to prevent rags from being sucked into the fan and also to prevent the nesting of birds. Numerous cases are known where rags and the like accidentally sucked in caused destruction of the rotor of a P.V.C. fan.

FIG. XVII/4.—Laboratory fume cupboard with fume washing and absorption system.

The packing of larger sized P.V.C. fans, especially for export, presents some difficulties. It is bad practice to despatch a fan assembled with its motor as the motor is usually considerably heavier than the fan and the case may get top-heavy and fall from the transporting vehicle. It is, therefore, recommended to despatch these in separate cases and to assemble on site; suitable instructions should be given for wiring up to make certain that the motor rotates in the correct direction, as rotation in the opposite direction unscrews the rotor and causes damage.

Fig. XVII/5.—Large P.V.C. fume cupboard for processing electronic components.

Fume Cupboards

The design of fume cupboards for chemical laboratories and processing plant has remained unaltered for a great many years. It is the general practice to build these fume cupboards from hardwood and glass and to use asbestos duct work and suitably protected steel fans to carry away the highly corrosive fumes.

More recently progressive laboratory furnishers have decided to re-design their fume cupboards and use some of the newer corrosion resistant materials; their obvious choice fell on rigid P.V.C.

A typical P.V.C. fume cupboard with sliding doors and windows

made from rigid, transparent P.V.C. is shown in Fig. XVII/4, a very much larger cupboard in Fig. XVII/5. The understructure is nearly always built in wood for economical reasons, but one or two laboratory furnishers fabricate even the understructure of their fume cupboards in rigid P.V.C.

The upper part of the fume cupboard houses a spraying system with baffle plates to wash and absorb the fumes effectively. Where necessary further spray nozzles can be installed to introduce ammonia for better absorption of highly concentrated acid fumes. Alternatively, a container with activated carbon can be built on for the same purpose.

It is general practice to change the volume of air inside the cupboard at least six times per minute and provision should be made for a sufficiently large duct system and a fan of ample capacity.

The temperature inside the fume cupboard may be quite considerable due to radiation from Bunsen burners, hot plates and other heating appliances; this will soften the top and the sides of the cupboard and unless suitable precautions are taken they will cave in and collapse once a vacuum is applied. Suitable reinforcements should therefore be provided and whenever possible melamine boards (Formica and the like) should be used for facing the inside of the cupboard, but leaving an air gap of approximately 1 in. between the melamine boards and the P.V.C. structure to reduce heat transfer.

A particular case where P.V.C. fume cupboards provide the only satisfactory solution is analytical work with perchloric acid. Wooden fume cupboards soon become impregnated with persalts and quite a few cases are known where the wood so impregnated caught fire, or where the entire cabinet exploded. P.V.C. fume cuboards are perfectly safe for this application due to the impervious nature of rigid P.V.C.; apart from this P.V.C. could not catch fire. Cleaning the inside of a P.V.C. cupboard to remove crusts of salt is also easier than with wood.

Pumps

Rotary pumps built from rigid P.V.C. were enthusiastically received by the chemical industry as soon as they appeared on the market, but unfortunately, they have not come up to expectations. Frequent failures have brought them into ill repute and a great deal of persuasion is often required to introduce one of these pumps to new customers.

Metal pumps, too, fail frequently when used with highly corrosive chemicals as most chemical manufacturers have the tendency to use one and the same pump for a variety of applications.

The main reason for the failure of P.V.C. pumps are the glands or packings.

These packings or glands are made from a flexible material, for instance, plasticized P.V.C., rubber and the like, which are not as corrosion resistant as the remainder of the pump. The weakest part,

in this case the packing or the gland, fails first and although the housing and the rotor may stand up to severe service conditions, a pump is, in effect, only as good as the packing or the gland.

Corrosion tables are often provided by pump manufacturers to indicate the chemical resistance of their pumps, but is often forgotten that the glands or the packings will not stand up to some of these chemicals and the pump will, therefore, fail in service.

Rotary P.V.C. pumps are usually produced in small batches—this is one of the reasons why they are so expensive. Both the housing and the rotor are machined from block—assembly of the individual parts is subsequently effected by welding. One firm has succeeded in producing moulded pump parts but these have still to be trued up afterwards.

The shaft bearing the rotor is obviously made of metal and has to be covered with a P.V.C. sleeve to make it corrosion proof.

The temperature limitations of P.V.C. pumps are often overlooked; P.V.C. pumps should not be used above 125° F. (50° C.) as higher temperatures cause the impeller to increase in size so that it will rub against the housing resulting in serious damage to the pump.

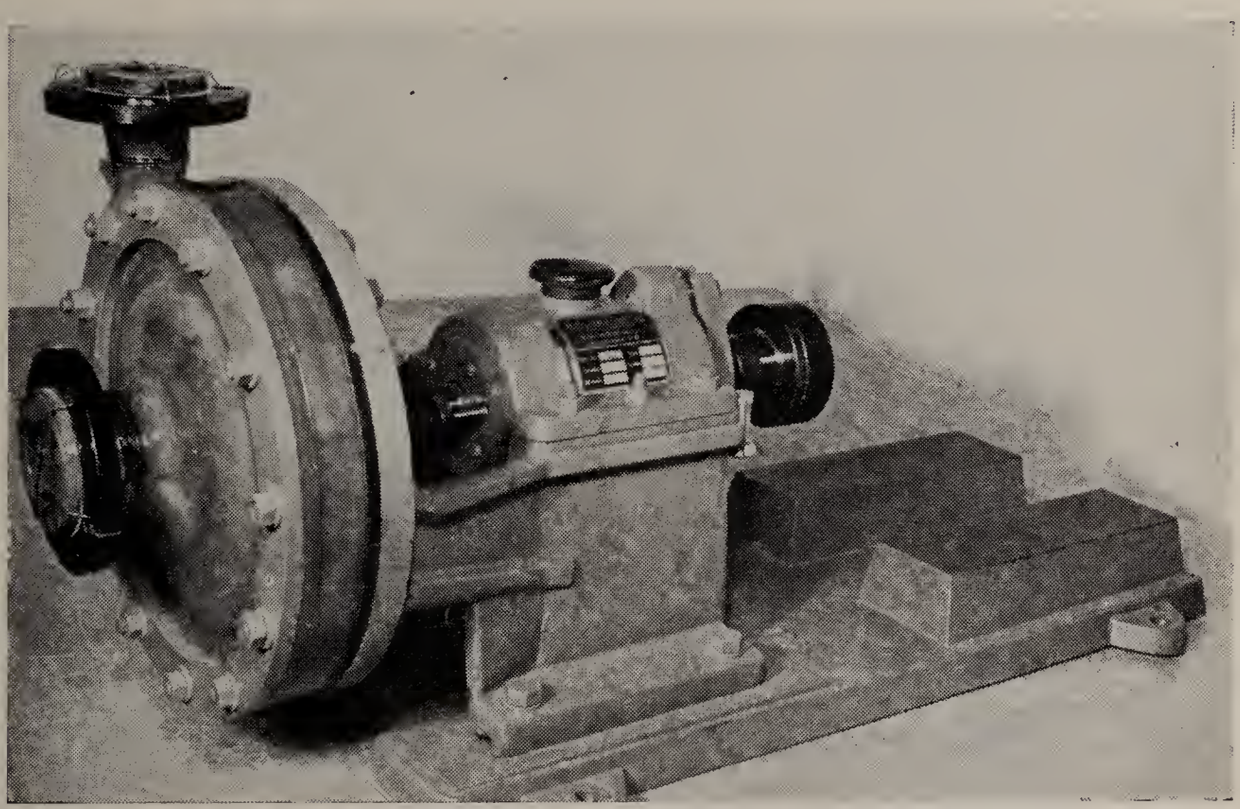

FIG. XVII/6.—Centrifugal pump for corrosive chemicals. Both rotor and pump housing moulded in rigid P.V.C.

Most P.V.C. rotary pumps are not self-priming, which is a serious drawback; lack of supervision and failure to fill the pump before use may cause the pump to run dry, resulting in the destruction of the rotor and damage to the housing. Self-priming devices and P.V.C. foot valves help a good deal to eliminate these troubles. Pumps should,

whenever possible, be installed in such a way that the inlet of the pump is situated below the level of the storage tank from which it draws its supply.

The wiring up of the motor of a P.V.C. pump is another matter which needs careful consideration. Cases are known where the motor of a P.V.C. pump was wrongly connected; this caused the rotor of the pump to turn in the wrong direction resulting in unscrewing of the rotor from the shaft and fracture of the rotor.

Such accidents can be overcome by fixing the rotor firmly to the shaft.

Fig. XVII/6 shows a well-known make of P.V.C. pump.

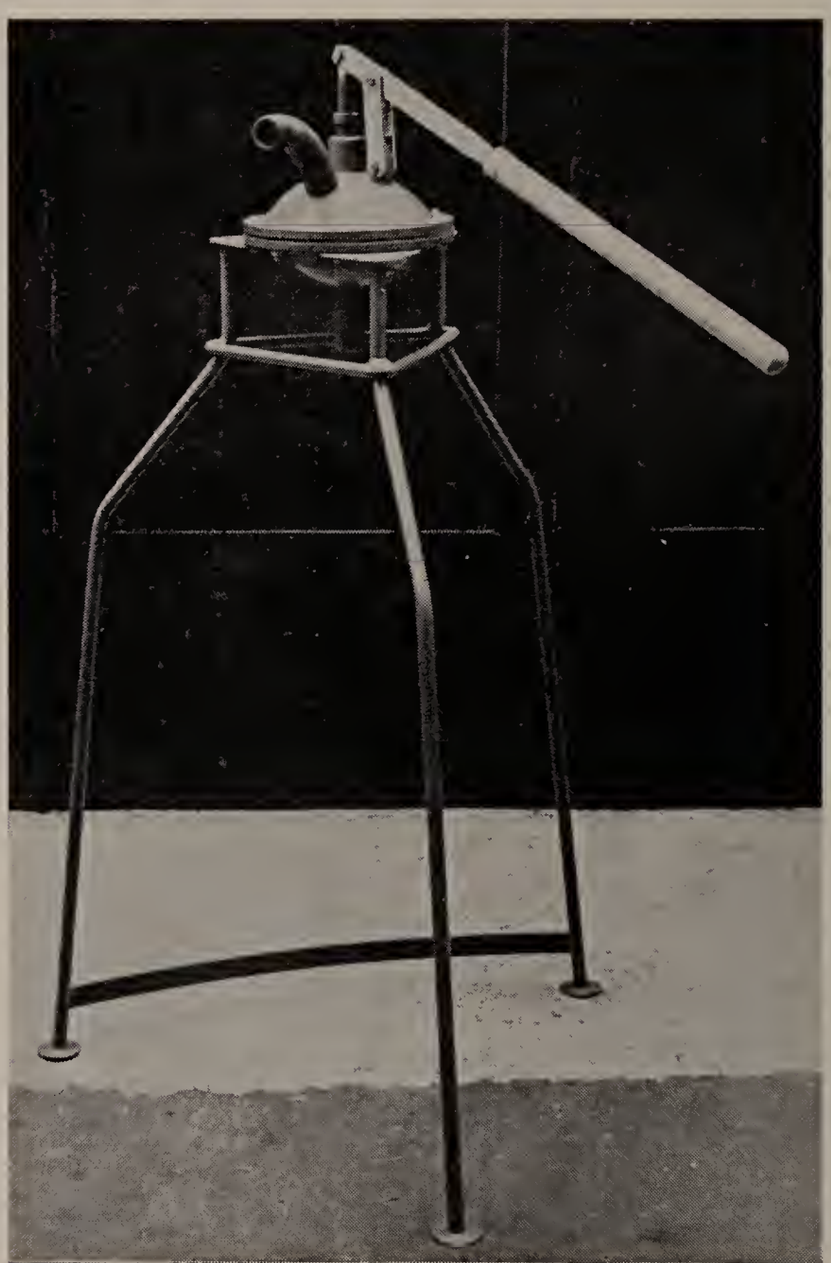

Fig. XVII/7.—P.V.C. diaphragm pump.

Other types of P.V.C. pumps are of the piston type or hand-operated diaphragm pumps. (Fig. XVII/7). The output of both types is strictly limited.

Valves

The large-scale use of corrosion resistant P.V.C. pipes led naturally to the development of equally corrosive resistant P.V.C. valves. As early as 1942 rigid P.V.C. valves were produced in Germany by the firm of Karl Canzler, and one or two others. The development work leading to this type of valve was described in a paper by Klant (*3*). Most P.V.C. valves are still machined from P.V.C. bar, rod and sheet and subsequently assembled by welding. Considerable quantities of these valves were produced during the last war for military applications and allied investigators found more than 3,000 of them at Kiel, where they were stored for assembly to form part of V.1 and V.2 rockets.

Canzler still produce this type of valve with minor changes only in design. It has been reported that girls are employed in their manufacture (for assembly work and welding) and it has also been stated that girls are far more efficient than men for this type of welding.

Similar valves are produced in Great Britain, in France, in Switzerland and in Italy. They all suffer from the inherent disadvantages of rigid P.V.C., i.e., they are brittle and can be damaged by spanners used for tightening up.

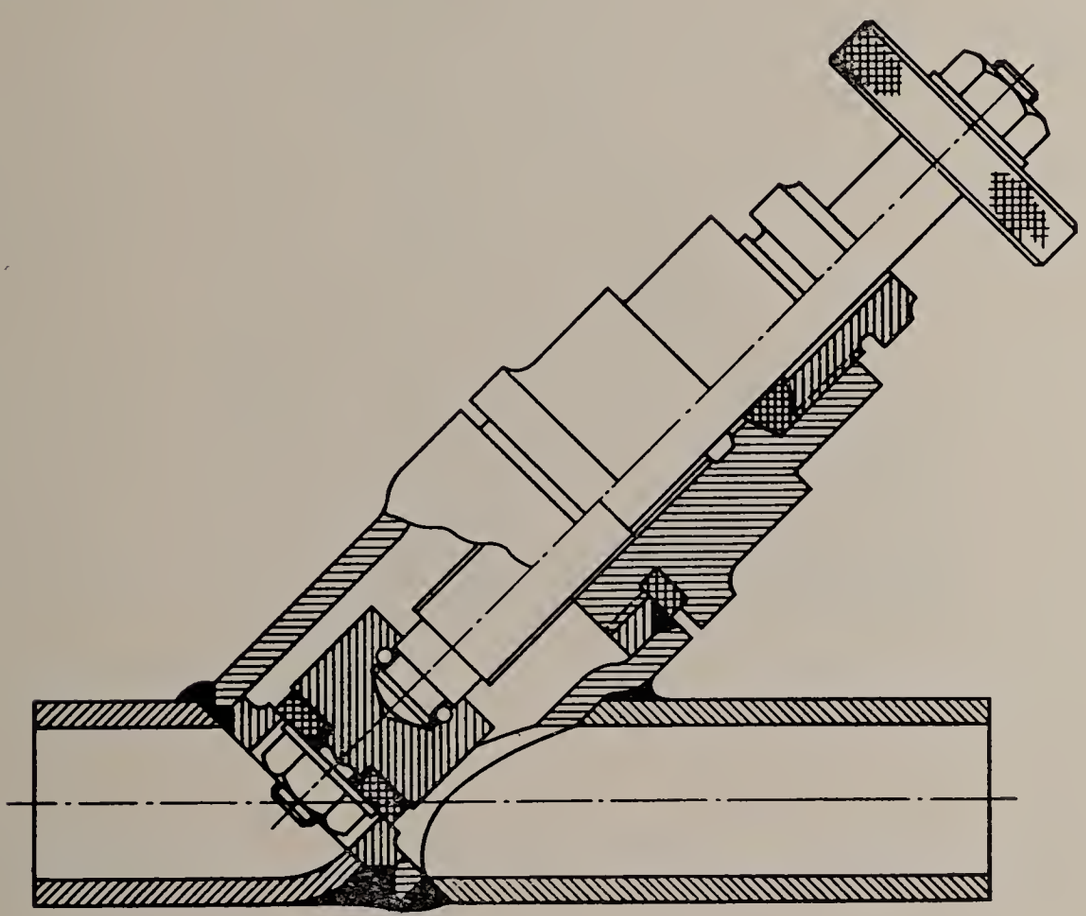

Fig. XVII/8.—Moulded P.V.C. valve.

Another disadvantage of most P.V.C. valves is restriction of flow inherent in the design, see Fig. XVII/8.

Wernert developed a moulded P.V.C. valve of improved design. This particular valve is offered in three sizes, i.e. $1\frac{1}{4}$, $1\frac{1}{2}$ and 2 in., but as the same standard mouldings are used for the whole range, restrictions in flow are caused and the connecting flanges only correspond to the actual bore quoted.

Moulded P.V.C. valves are also produced in Italy and in the United States. The Lunkenheimer valve (Fig. XVII/9) is produced in high impact P.V.C. and will stand up to 125 p.s.i. at 140° F. It is of excellent design and has a packing consisting of self-lubricating Teflon. The thread used is of the Acme type which overcomes some of the disadvantages of other types of valves. The flow through this valve is still somewhat restricted. Lunkenheimer produce a full range of valves from $\frac{1}{2}$ in. to 2 in. bore.

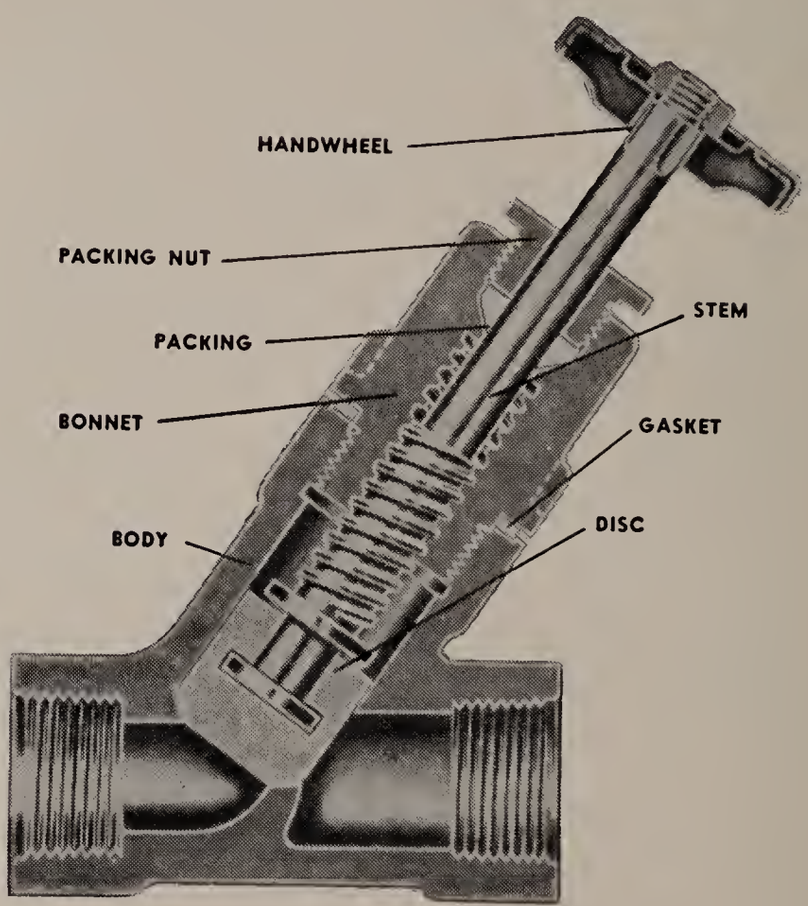

Fig. XVII/9.—Moulded P.V.C. angle valve.

Several years ago a German firm introduced armoured P.V.C. screw down valves but as far as can be ascertained they are no longer on the market.

The Hills-McCanna Company, U.S.A., offers P.V.C. diaphragm valves; the lower body of these valves is moulded in rigid P.V.C. The development of this valve was described by R. McFarland Jr. (*4*). Hills-McCanna claim that their valve will stand up to 150 p.s.i. at 70° F. in sizes up to 2 in. At 150° F. the working pressure is obviously

lower but still satisfactory for most applications. The diaphragm of these valves consists of Teflon, Polythene, rubber, Neoprene or Hypalon.

Similar diaphragm valves are offered in Great Britain by the Saunders Valve Company Limited.

Also a diaphragm valve, but of slightly different design, is the Warren Morrison valve.

The old complaint that screw-down P.V.C. angle valves have a somewhat restricted flow has been apparently overcome by a new design by Kunststoff-und Plastetechnik, Germany. The seating of their KPT valve is so arranged that the liquid passes through without hindrance. Similar ideas must have influenced the designers of the new Vanton valve.

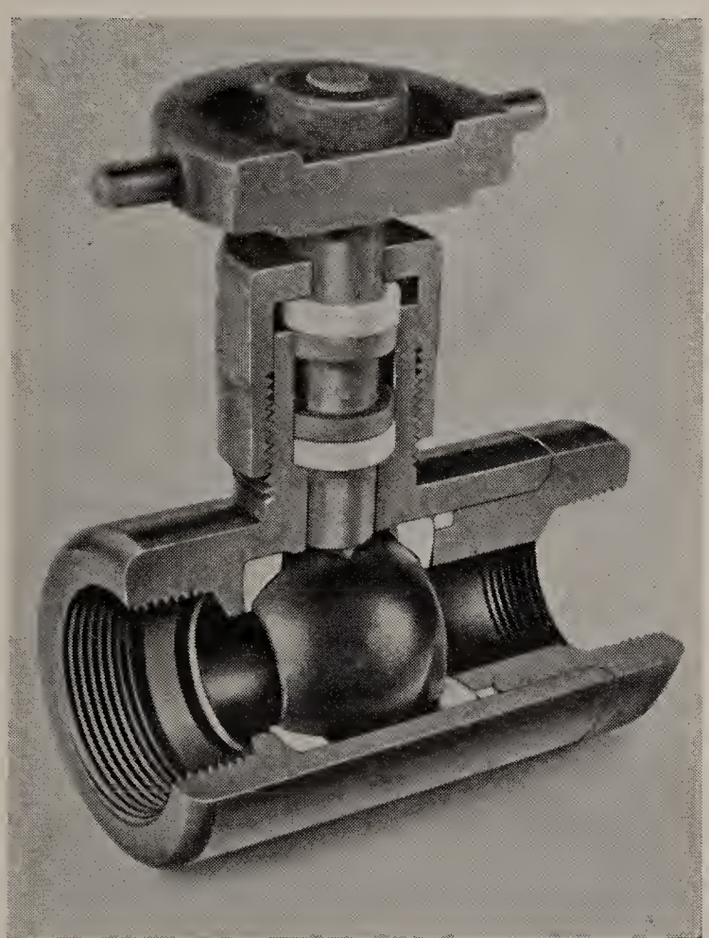

FIG. XVII/10.—Jamesbury Valve fabricated from rigid P.V.C. and Teflon moulded sections.

Rigid P.V.C. ball valves do not suffer from the disadvantages of screw-down valves. They allow perfect flow of the liquid, hold pressures up to 150 p.s.i. and can easily and positively be closed without wrenches or tightening tools. A cross-section through a typical ball valve, the Jamesbury valve, is shown in Fig. XVII/10.

The ball is held by specially shaped Teflon rings which are self-lubricating. There are two further Teflon rings to tighten up the

FIG. XVII/11.—Transporting screw in P.V.C. mounted on steel shaft.

stem. The valve opens up completely when the P.V.C. ball is turned 90°, i.e. the tedious screwing operation necessary with screw-down valves is avoided.

P.V.C. stopcocks are of minor importance to chemical plant. They are especially subject to the disadvantages of rigid P.V.C., i.e. they cannot be precision ground like glass stopcocks, and therefore leak frequently.

A paper by R. B. Seymour in *Chemical Engineering* (*6*) describes a variety of plastic valves and reviews them critically.

The Chemical Industry Proper

There is a widespread belief that rigid P.V.C. is not sufficiently strong to allow for its use for large chemical plant. Some of the illustrations shown in this chapter will convince engineers and designers of plant that rigid P.V.C. can be used for purposes where previously stainless steel, nickel, monel metal and non-ferrous materials were employed.

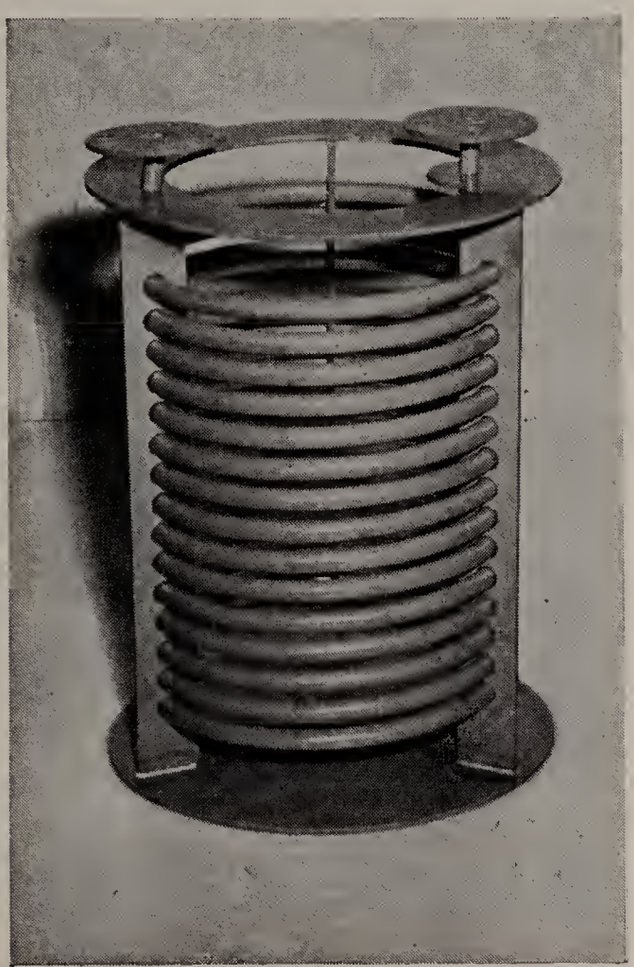

Fig. XVII/12.—P.V.C. Cooling coil fabricated from 1 in. bore rigid P.V.C. tubing.

Care has been taken in the selection of the photographs to make certain that only plant and equipment is represented which has given satisfaction in use for at least five years.

An interesting application—a transporting screw mounted on a steel shaft also covered with P.V.C. is shown in Fig. XVII/11. It should be noted that the blades of the screw were fabricated from discs which were individually preheated and then placed on the shaft using a slight twisting movement. The blades were subsequently welded to the shaft and a transverse weld was made across every blade where it was split.

Cooling coils are rarely made from rigid P.V.C. but there are conditions where metals are unsuitable for this purpose because of the corrosive nature of the liquids employed.

FIG. XVII/13.—P.V.C. ring balance for gas metering device.

A cooling coil fabricated from 1 in. bore rigid P.V.C. tubing is shown in Fig. XVII/12. The spacing by means of three flat P.V.C. strips is of interest. Similar cooling coils fabricated from very much larger pipes up to 3 in. in bore, have been produced by various firms.

Parts of valuable instruments used in chemical works may be in contact with highly corrosive liquids or gases and therefore perish in due course, whilst the remainder of the instruments is still usable. The introduction of P.V.C. into the field of instrumentation has opened new lines of design. Typical examples are the P.V.C. ring balance shown

in Fig. XVII/13, the ammonia analyser, Fig. XVII/14, and metering devices such as those illustrated in Fig. XVII/15. Both devices—the analyser and the metering units are intirely fabricated from P.V.C.

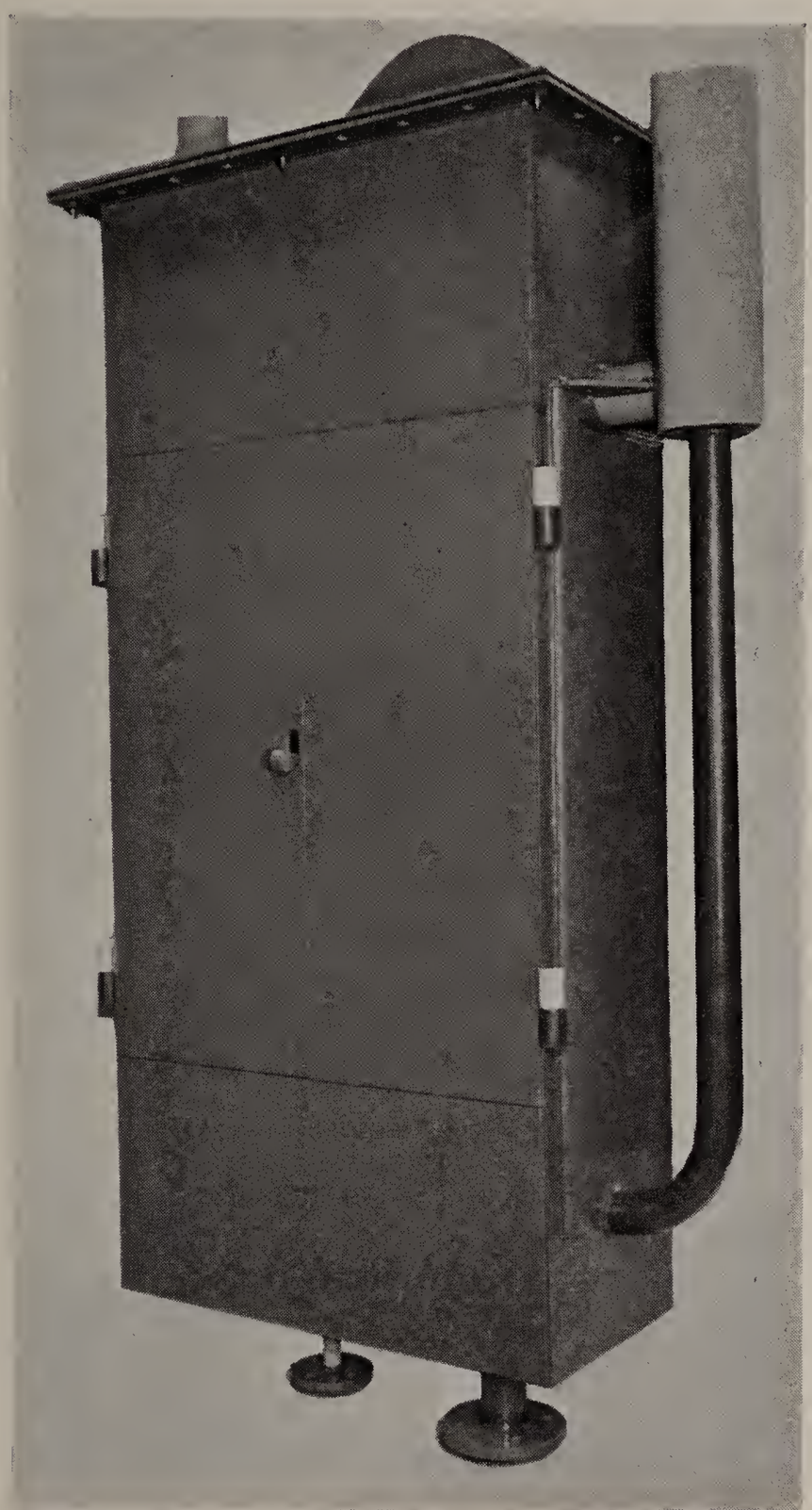

FIG. XVII/14.—Ammonia analyser fabricated in rigid P.V.C.

Each of the five metering units consists of a trough on which a shaft, bearing discs, is mounted. Each disc in turn carries ten cups of a given capacity. The discs rotate at a predetermined speed, and the beakers in

descending discharge their contents into trays, the outlets of which are connected to a common outlet. The capacity of the plant depends on the size or capacity of the cups and on the speed of rotation. These can be varied within reasonably wide limits, and as several units can be built together, a relatively high output can be achieved. In cases where only small quantities of liquid have to be measured one or two disc units may be sufficient.

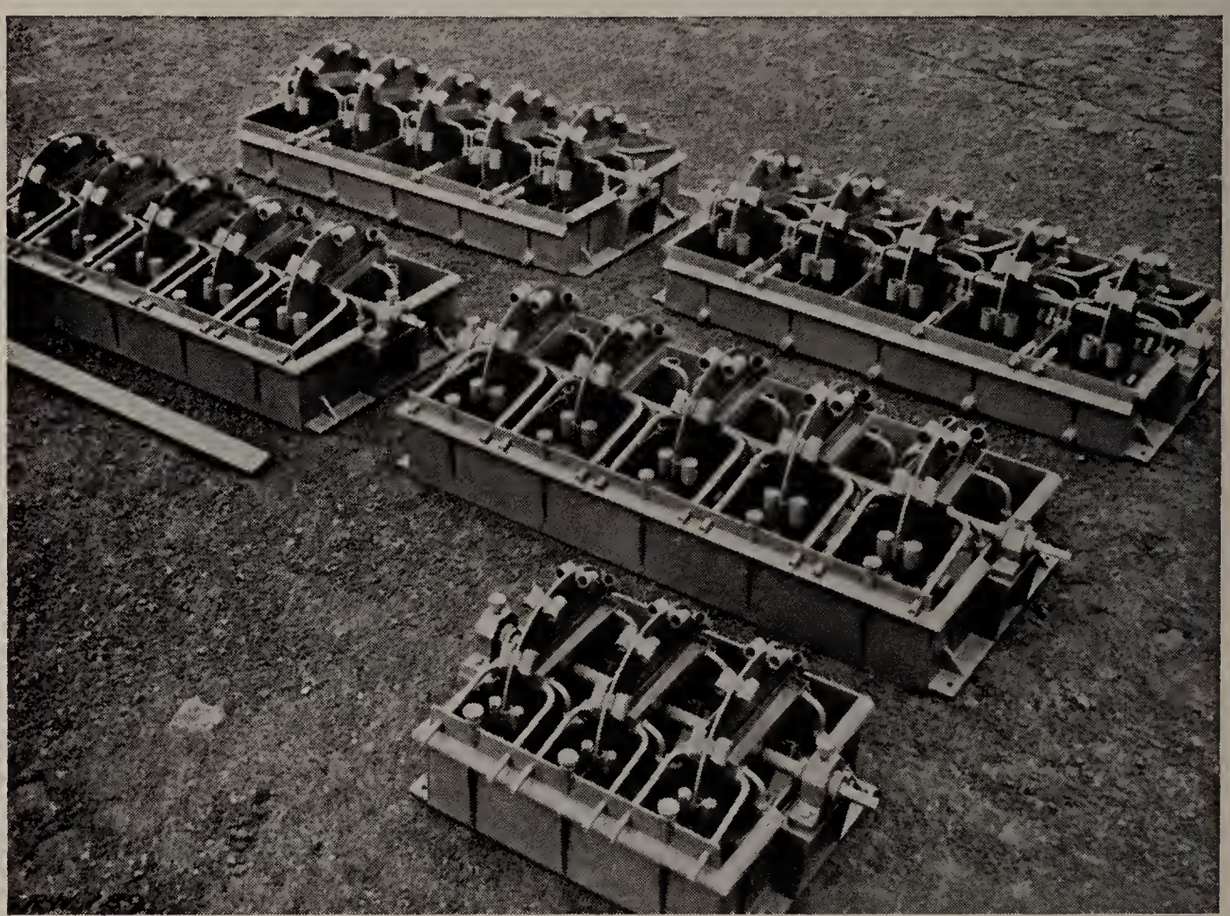

FIG. XVII/15.—Metering devices for corrosive liquids.

A Drum Filter with agitation tank and agitator is shown in Fig. XVII/16, the actual drum in Fig. XVII/17. The drum measures 8 ft. in length and has a diameter of 3 ft. on one end and 2 ft. at the other; the perforations are $\frac{1}{2}$ in. in diameter. The centre shaft is hollow and lined with P.V.C. on its inside and the outside is also covered.

Large size rotary drum filters are fabricated in steel and subsequently lined with perforated sheets of rigid P.V.C.; the end plates are covered with plasticized P.V.C. sheet. The liquid is drawn through the perforations and into a pipe system under vacuum leaving through the internally lined hollow shaft of the filter unit, Fig. XVII/18.

Reaction towers and scrubbers of considerable size are frequently constructed in rigid P.V.C. One of these towers, approximately 8 ft. high, is shown in Fig. XVII/19. Some of these towers are fitted with show glasses and inspection windows made from transparent P.V.C. and welded to the shell of the tower.

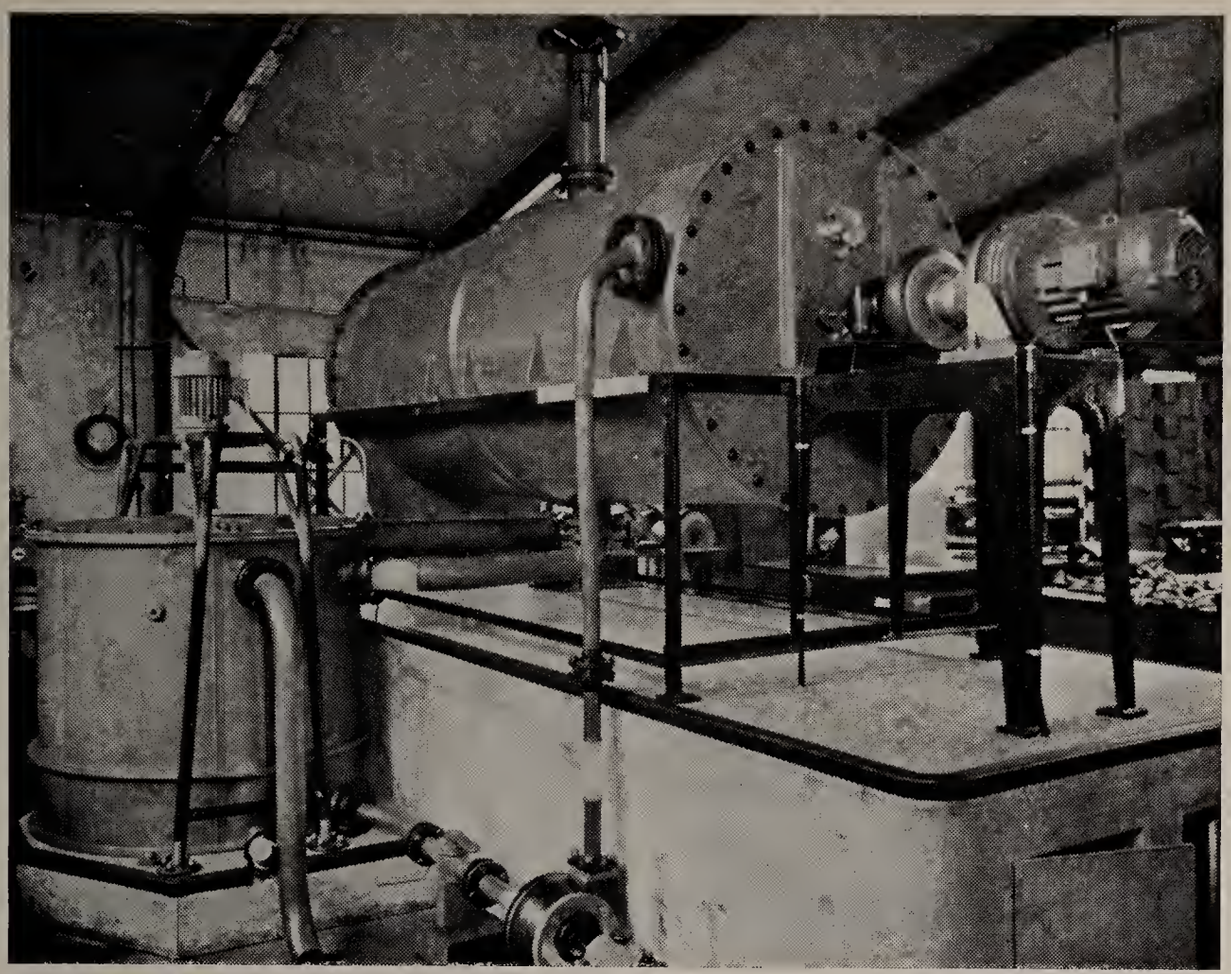

FIG. XVII/16.—P.V.C. drum filter and agitation tank.

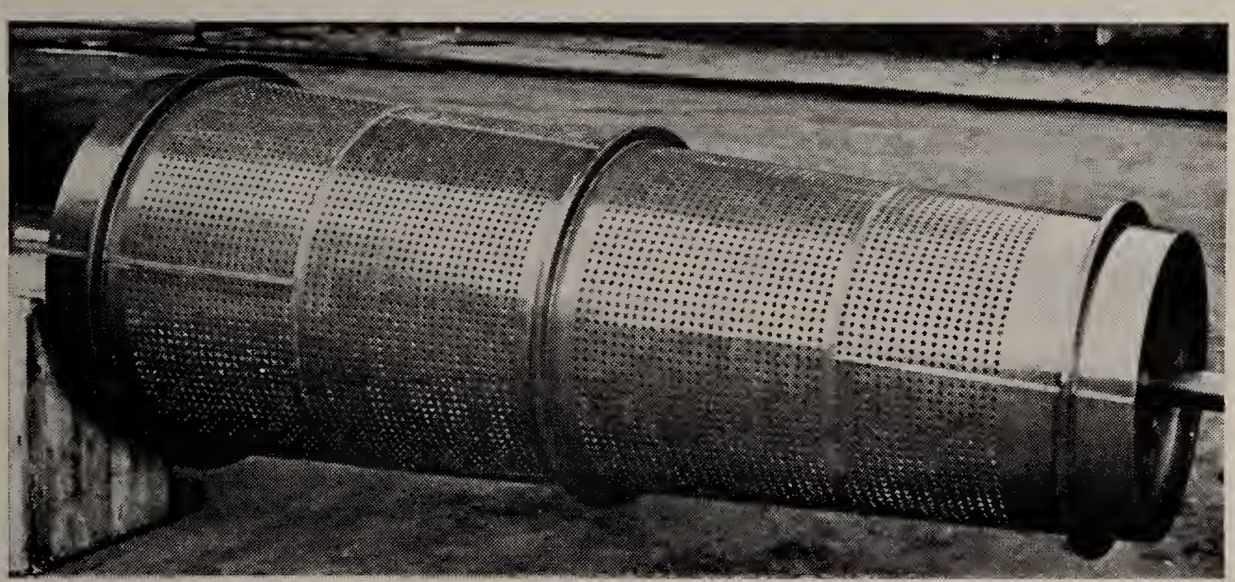

FIG. XVII/17.—P.V.C. drum 8 ft. long × 3 ft. wide. This particular drum is part of the installation shown in Figure XVII/16.

A complete absorption plant for nitrous acid gases, consisting of three P.V.C. towers 16 ft. high and 2 ft. in diameter, is shown in Fig. XVII/20. The turbo blowers, pumps, pipelines and valves are all constructed in rigid P.V.C. Further details of this plant, which was first shown at the ACHEMA in 1951, are given below.

The waste gases containing nitrous oxide fumes are led from the third acid tower via a cyclone with a separator for liquids to a mixing nozzle, where the last nitrous oxide gas particles are thoroughly mixed with air, so that they are fully oxidized.

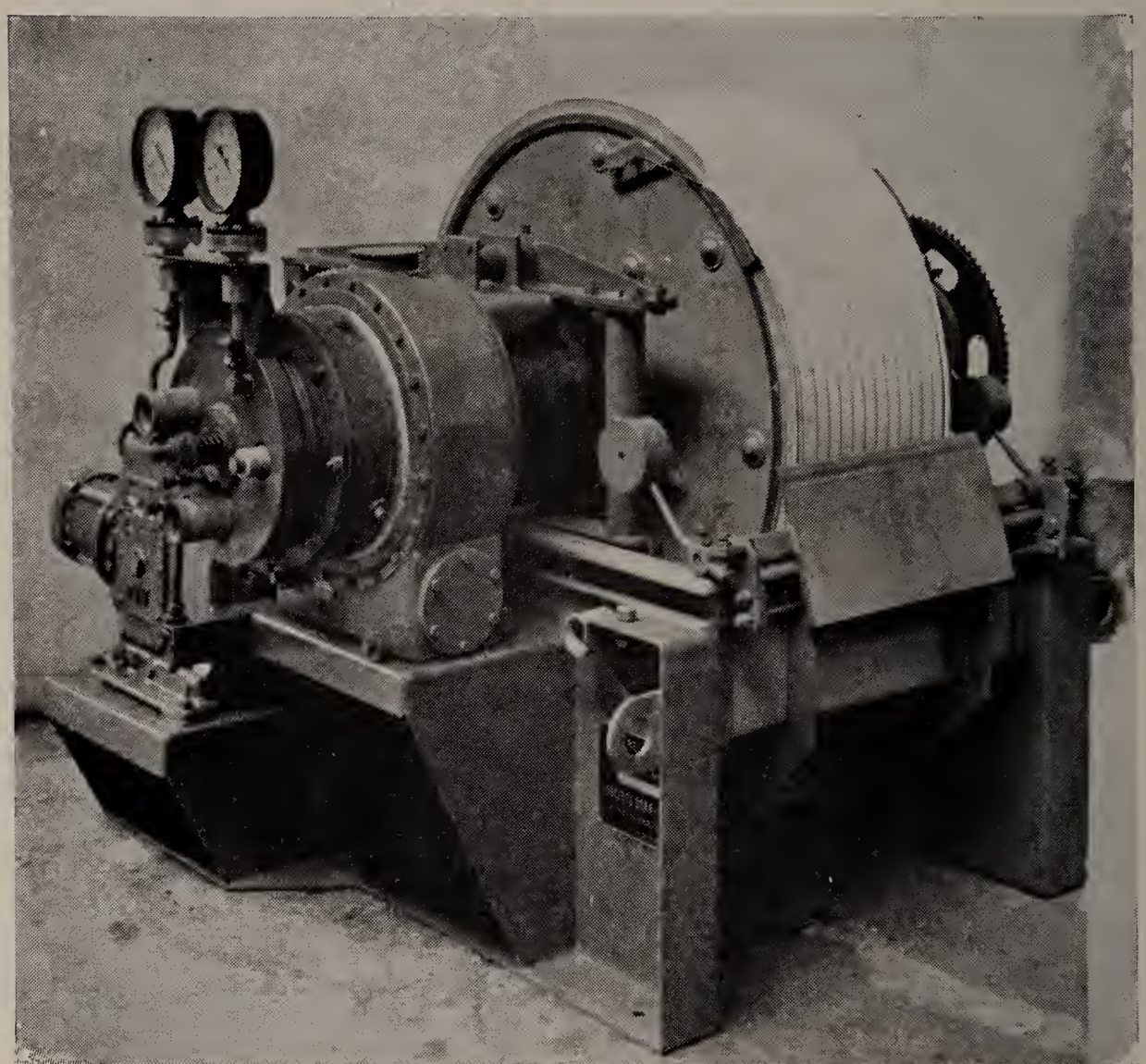

Fig. XVII/18.—Rotary filter fabricated mainly from rigid P.V.C.

The nominal capacity of this plant is 5,250 cu. ft./hour. The fan has a capacity of 12,600 cu. ft./hour at a pressure of 280 mm. water gauge. It is driven by a 1-Kw. motor at 2,800 r.p.m. (the ventilator should draw 5,250 cu. ft. of gas per hour). Each of the absorption towers has a diameter of approximately 20 in. The Raschig rings in the absorption towers are made of either porcelain or P.V.C. Collecting troughs are located approximately half-way up inside the tower to distribute the washing liquid, which runs down the walls of the tower, which is then distributed through these collecting troughs over the remaining Raschig rings. Each tower requires approximately 300 gallons of water per hour. Special spray nozzles are fitted inside the towers, with filter units inserted to prevent blocking.

Off-cuts from rigid P.V.C. pipes are often used as tower packings for absorption towers and columns in chemical factories. They are very much lighter in weight than ceramic packings (Raschig rings, Pall rings, etc.); towers to be filled with P.V.C. packings can be of lighter construction and the saving in costs is considerable. P.V.C.

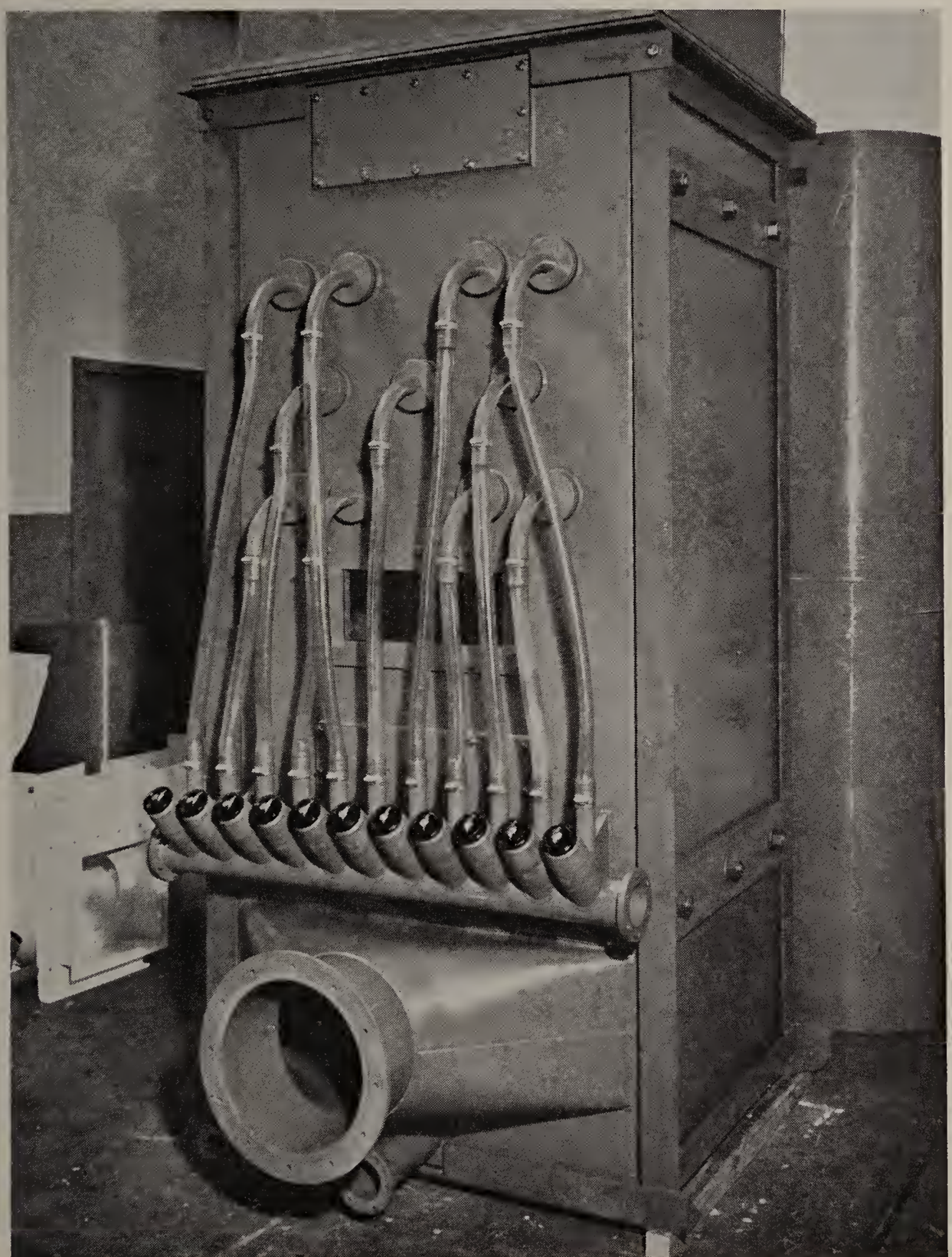

FIG. XVII/19.—Lower part of scrubbing tower for corrosive gases fabricated in rigid P.V.C. The flexible connections are made from transparent (plasticized) P.V.C.

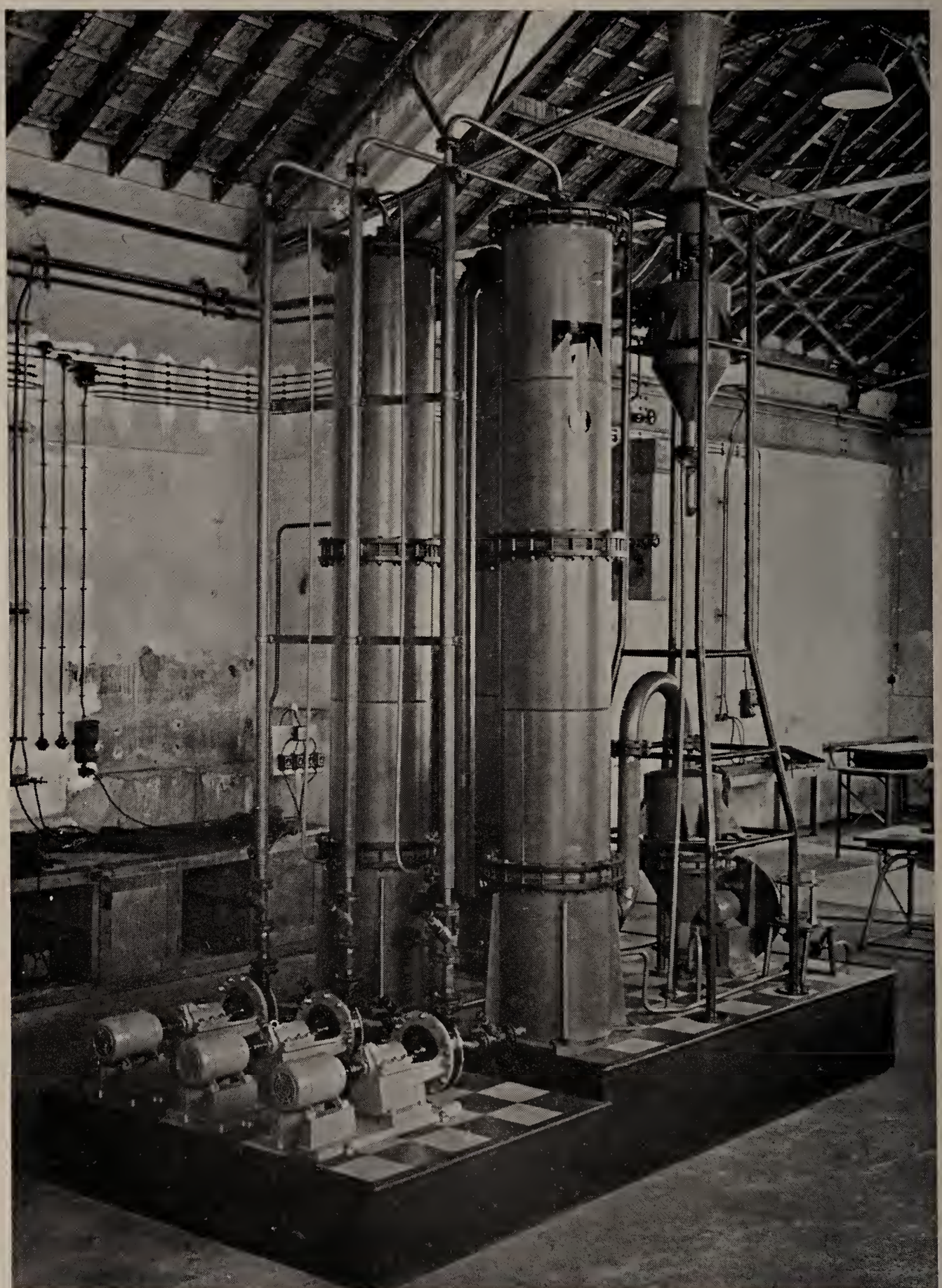

FIG. XVII/20.—Nitric acid absorption plant fabricated in rigid P.V.C. with P.V.C. turbo blowers, pumps, pipelines etc.

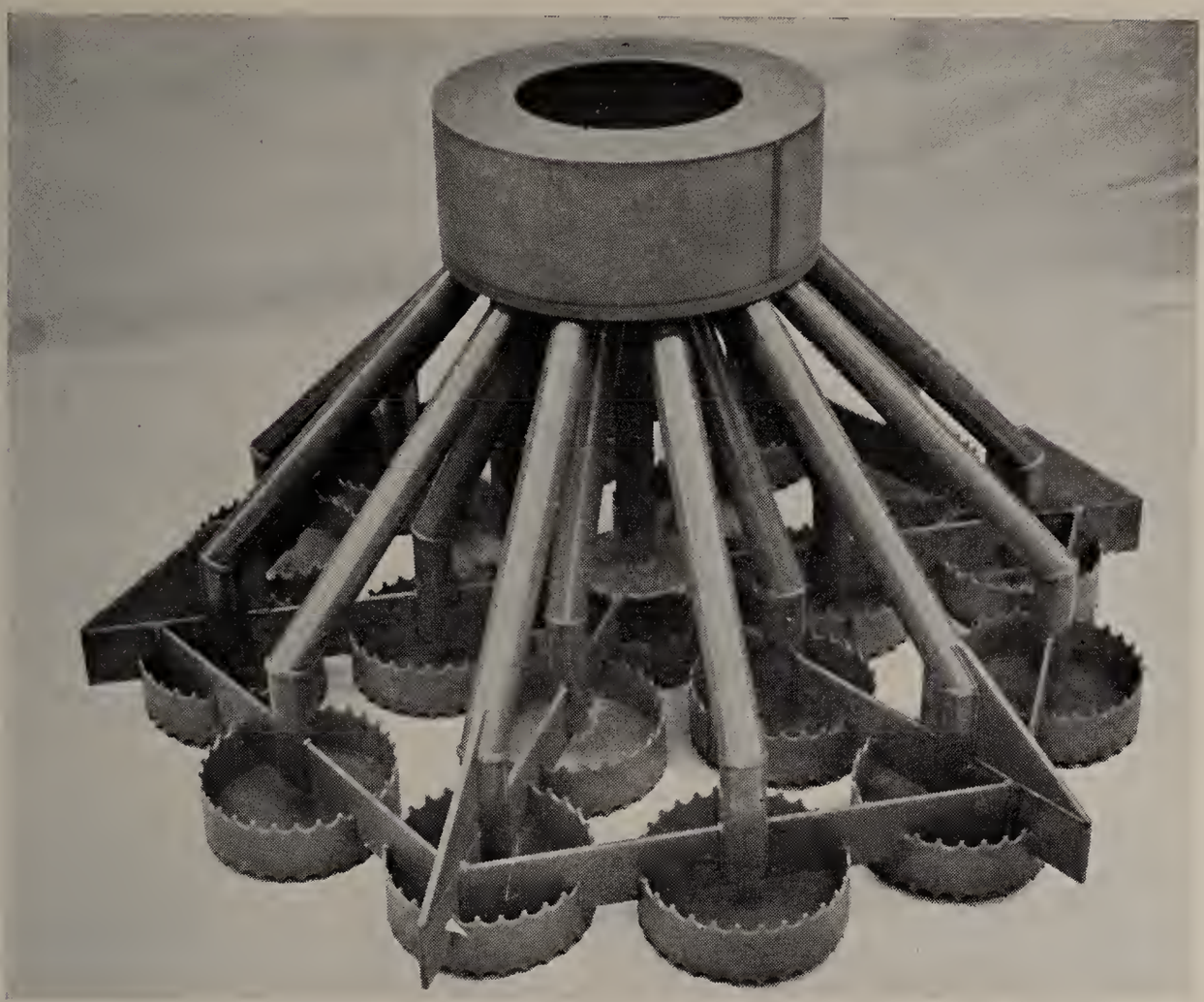

FIG. XVII/21.—Acid distributor fabricated from rigid P.V.C. sheet and pipes, 6 ft. diameter × 3ft. 6 in. high.

packing rings are also less liable to breakage and fracture than ceramic rings—another factor in their favour.

Their only adverse feature is temperature limitation—they cannot be used at temperatures exceeding 160° F. (70° C.).

An acid distribution system entirely fabricated from rigid P.V.C., Fig. XVII/21, measuring 6 ft. in diameter and 3 ft. 6 in. in height, carries specially shaped dishes on the end of each distributor pipe. These are drilled in pairs and parted off in the centre, thus providing the serrations on the rim of these dishes.

A further part of this distribution system is to be seen in Fig. XVII/22.

The sodium-hypochlorite filter plant, Fig. XVII/23, consists of P.V.C. valves, filter tubes and is mounted on top of a P.V.C. lined steel storage tank.

The large weathering cowl forming part of a huge chimney, Fig. XVII/24, clearly shows the staggered welds and the clamps which hold the individual rings together.

Fig. XVII/25 illustrates an aluminium condenser fitted with P.V.C. cooling tubes, Fig. XVII/26 a number of P.V.C. fume hoods in a laboratory.

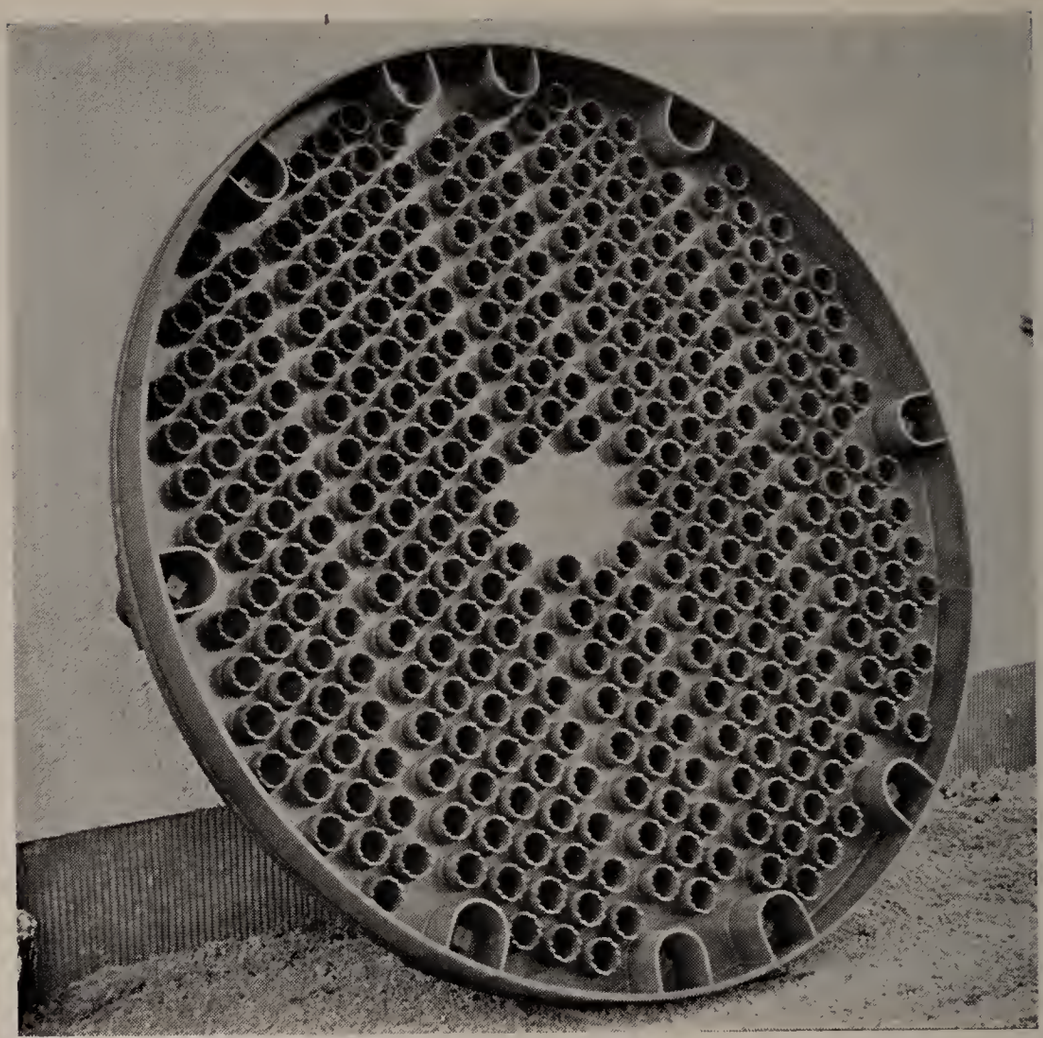

FIG. XVII/22.—Rigid P.V.C. bubble tray for absorption tower.

FIG. XVII/26.—P.V.C. fume hoods and ducts in a research laboratory.

Really large-scale installations are frequently made; these concern chimneys, cooling towers and large pipe lines.

The P.V.C. chimney shown in Fig. XVII/27 was erected at the Bayer factory, Leverkusen; it is almost 400 ft. high and measures 20 in. in diameter. The individual sections are approximately 15 ft. long and sleeved. Expansion pieces are provided to deal with the considerable changes in dimensions depending on the weather conditions.

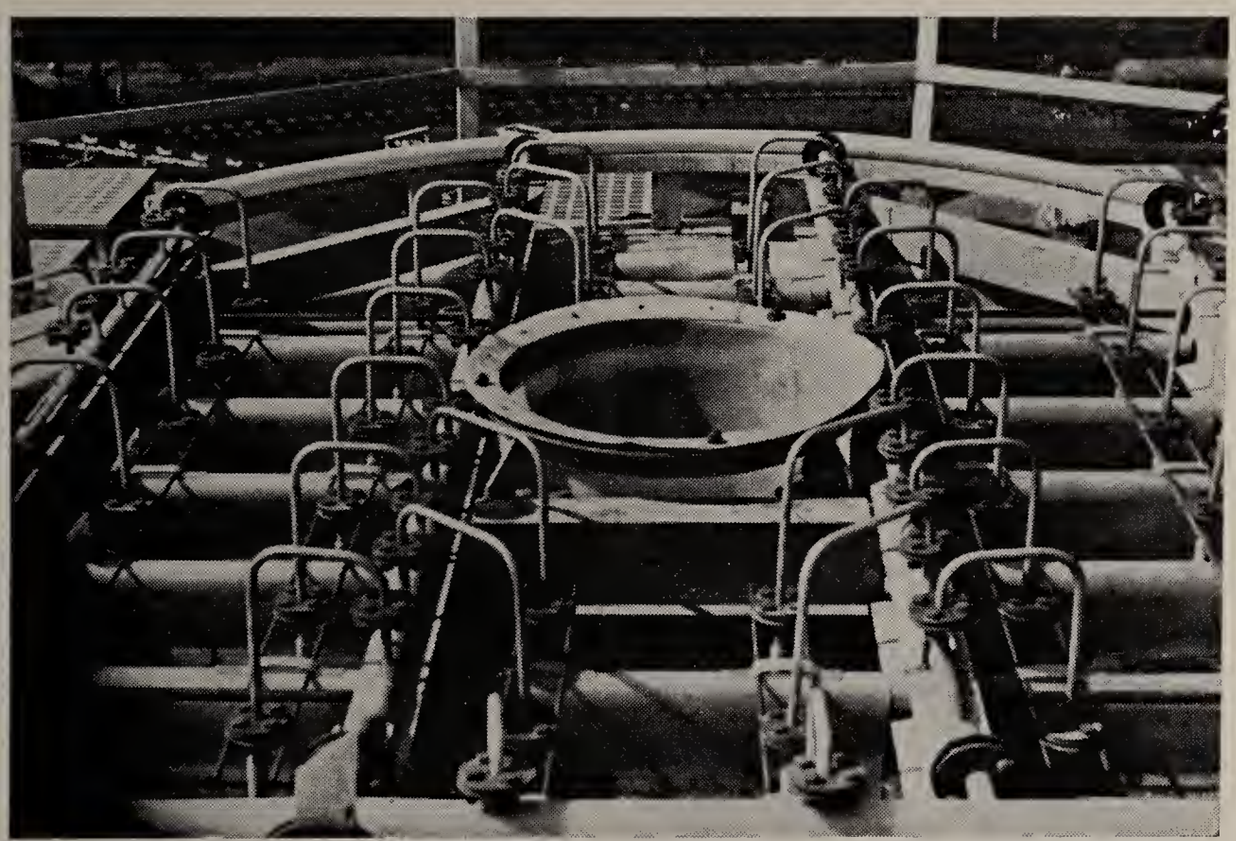

FIG. XVII/28.—P.V.C. pipework on top of the filter tower shown in the Frontispiece.

The chimney is used for conveying nitric acid gases. The brick chimney to which this P.V.C. chimney is attached was rather old, and the management of the factory did not consider it safe to pass the nitric acid gases through the inside of the old chimney, which had already been subjected to a fair amount of wear and tear. It was decided, therefore, to build a new duct system and to fix it to the outside of the chimney.

Even more impressive are the reaction towers and the filter towers of the Kachkaroff sulphuric acid plant; two such plants have been erected recently in the United Kingdom, several others on the continent.

The frontispiece shows the filter tower in the fore-ground, the reaction towers in the back-ground.

The filter tower measures 45 ft. in height; the actual P.V.C. part

measures 13 ft. (height) by 10 ft. in diameter, the corresponding figures for the reaction towers are the following:—

Height	40 ft.
Length inside P.V.C.	16 ft.
Breadth inside P.V.C.	10 ft.

The towers are constructed in wood, mild steel and concrete and lined with rigid P.V.C. $\frac{3}{32}$ in. thick.

The main tanks at these plants are made of mild steel and are also lined with $\frac{3}{32}$ in. thick rigid P.V.C. Alternatively, they are made from timber and drape lined with $\frac{3}{32}$ in. thick P.V.C.

Most of the pipe work in Kachkaroff plants is fabricated from P.V.C. varying in bore from $\frac{1}{4}$ in. to 20 in. Maximum operating pressure is 65 p.s.i. Fig. XVII/28 illustrates the top of a filter tower and shows the acid distributors and the gas outlet. Fig. XVII/29 shows the top section of a Gay-Lussac Tower fabricated from rigid P.V.C.

Finally, mention should be made of the huge P.V.C. earth gas main passing through part of the Po Valley in Italy. Built several years ago it extends over a length of 30 miles and has a bore of 27 in.

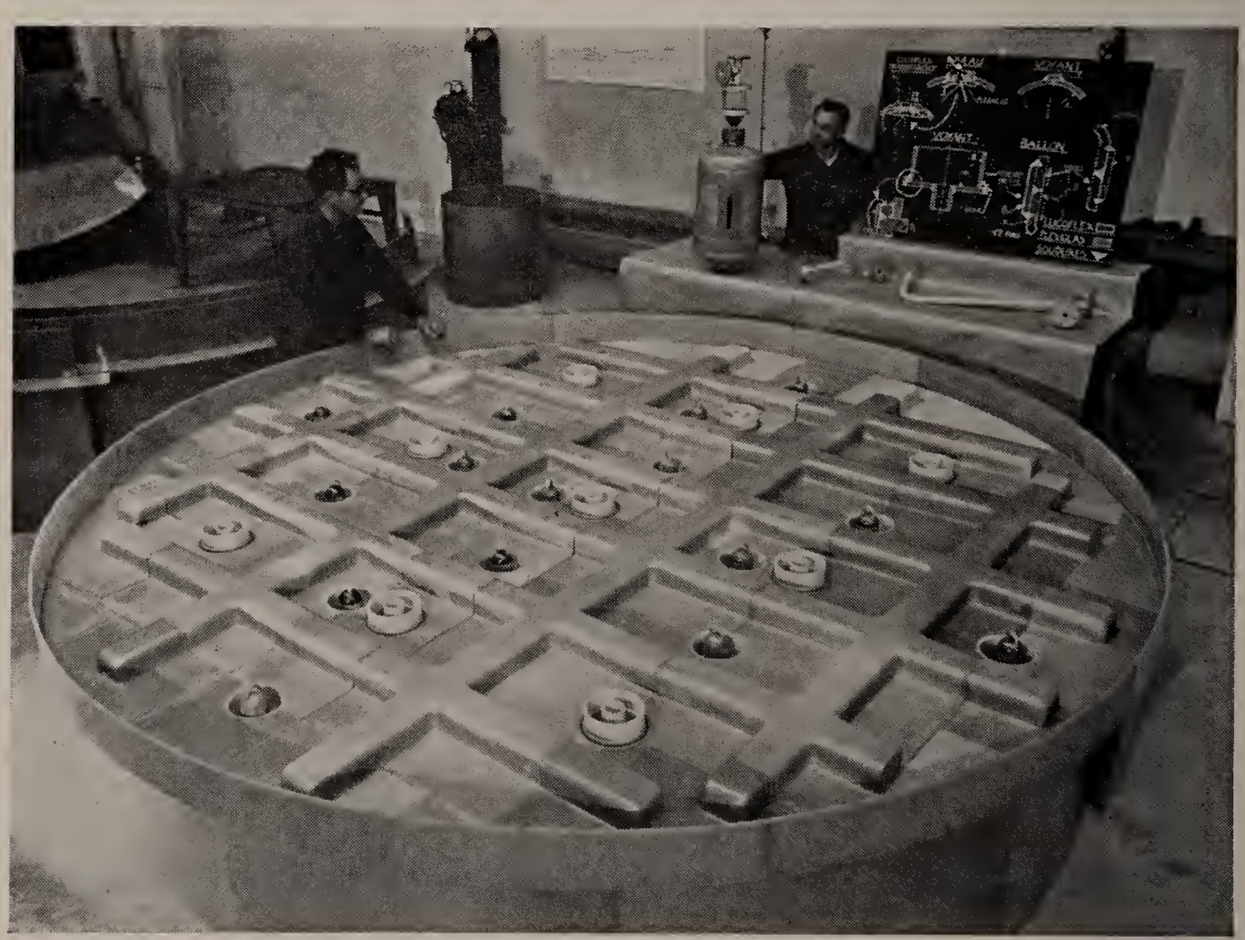

Fig. XVII/29.—Top section of Gay-Lussac Tower fabricated from rigid P.V.C.

Allied Industries

The aircraft industry

Numerous applications have been found for rigid and plasticized P.V.C. in this industry. P.V.C. scores here over most other plastic materials due to the fact that it is non-inflammable. P.V.C. floors and upholstery (leathercloth), P.V.C. textiles in the form of seat covers and curtains are some of the items of major interest.

Further applications are transparent instrument covers, trays, hoses and many other smaller items.

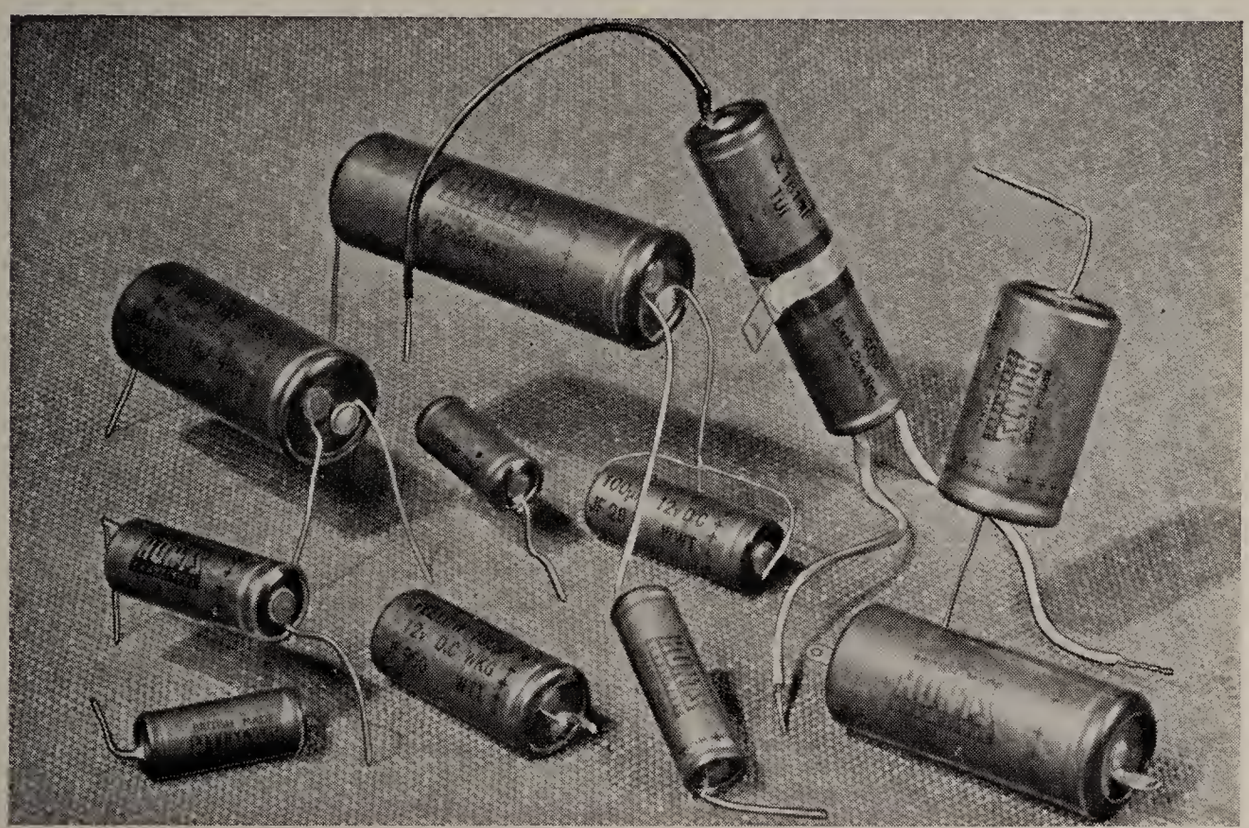

Fig. XVII/30.—Capacitors covered with shrunk-on P.V.C. tubing.

Artificial silk and rayon industry

There are large scale potential applications for rigid P.V.C. in the artificial silk and rayon industry, for instance, fume ducts and fume hoods over spinning machines. Some very large installations have been made for this industry, especially in Germany, with excellent results. Guiding rollers, spinning pots and impervious floorings are other known applications in this industry.

Rigid P.V.C. ducts were employed for some time in the American rayon industry, but they were not very popular, especially with the lead burners, who objected to the installation of plant by outside contractors. This eventually led to the installation of steel fume ducts coated on both sides with P.V.C. plastisols, subsequently baked on, a method developed by Quelcor Incorporated.

Some leading American and Canadian rayon factories now have their own plastisol coating plant; sections which have worn in use or have become damaged can thus be recoated without much delay. It is reported that these steel ducts, so coated, are a much more economical proposition than rigid P.V.C. ducts.

Electrical industry

Rigid P.V.C. tubing is nowadays accepted by many authorities in place of steel or other types of conduit.

Good insulating properties, light weight and resistance to corrosion make P.V.C. tubing ideally suited for this purpose.

A cheap and easy process for covering capacitors, condensers and the like with an insulating, pre-stressed sleeve of P.V.C., has been invented by Hagen, see Fig. XVII/30. Details of this process are given on pages 47 and 48.

Electro chemical plant

The electro chemical industry offers a wide scope for the applications of both rigid and plasticized P.V.C.

Pipe lines and ducts with valves and fans, tank linings and acid-proof floors, are only a few examples for this type of work. A somewhat unusual application are rigid P.V.C. supports for bus-bars over vats in electro metallurgical plant. Some years ago more than 100 tons of rigid P.V.C. sections were installed in France for this purpose.

Battery cases

According to BIOS report No. 1839 (*1*) rigid P.V.C. battery cases were fabricated in Germany during World War II when rubber and ebonite were no longer available. These battery cases gave reasonable service, but prices were too high and as far as can be ascertained their manufacture was given up after the war. Foamed or perforated P.V.C. battery separators are becoming increasingly popular.

Electroplating

Extensive use is made of P.V.C. in electroplating installations; the inert nature of the material and its excellent insulating properties are some of the reasons for the steadily growing demand for P.V.C. plating equipment and accessories.

Galvanizing drums, usually hexagonal, are fabricated from thick P.V.C. sheet; reinforcements are welded on to give greater strength. A P.V.C. gear wheel is provided on one side. Hinged lids facilitate emptying of the drum. (Fig. XVII/31).

Further applications are pickling units (see pages 271–275), fume ducts, pipe lines, tanks, tank linings and filter units.

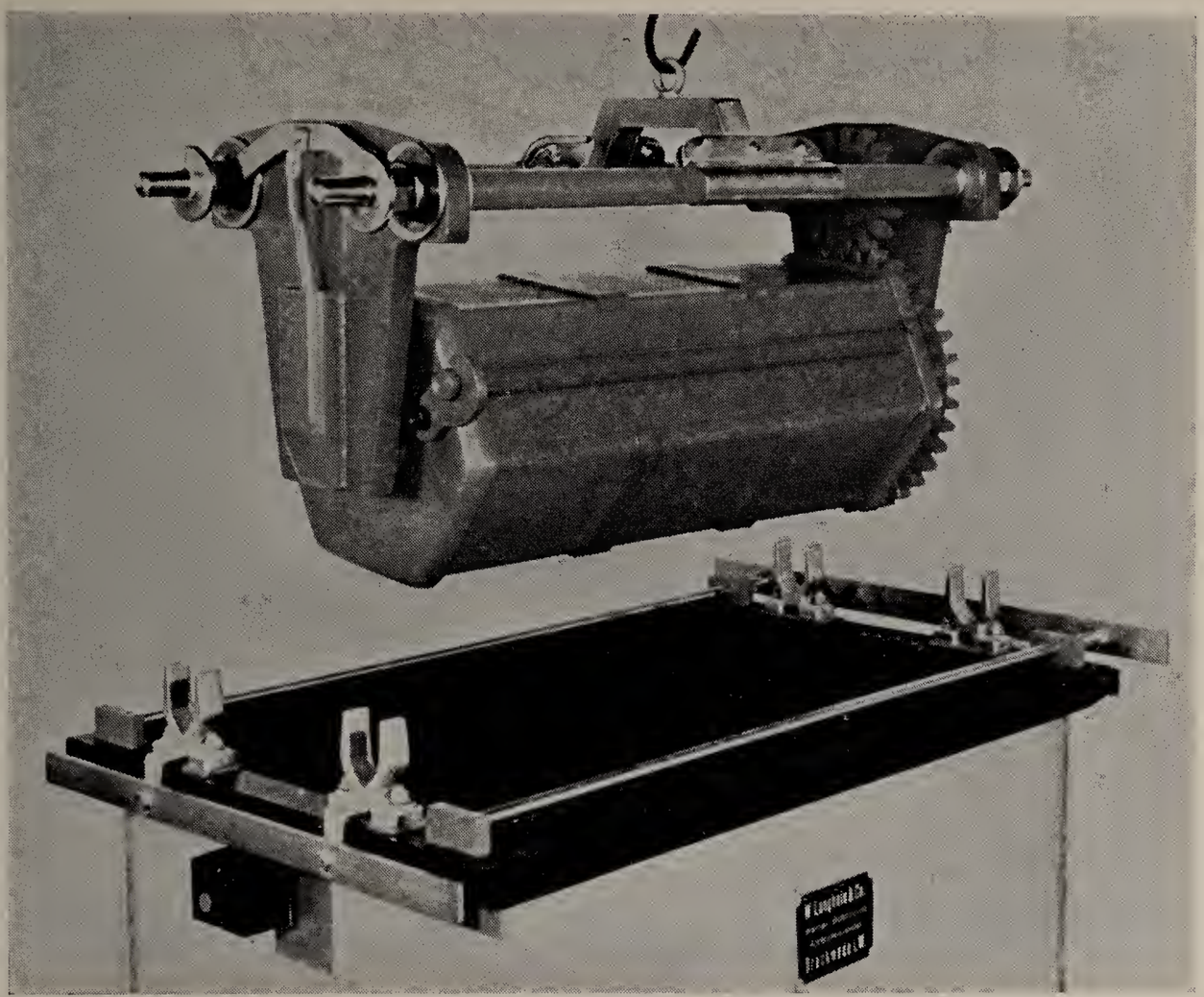

FIG. XVII/31.—Hexagonal plating barrel fabricated from rigid P.V.C.

A typical P.V.C. filter unit designed for work in plating shops is shown in Fig. XVII/32. The pump of this unit is fitted in a vertical position, with an all-enclosed motor located on top of the pump. The plating solution is fed through a flexible P.V.C. hose to the body of the filter and is recirculated from the top of the filter to the tank. An expanded P.V.C. or Polythene basket inside the filter unit supports a P.V.C. filter bag, which retains sludge and other foreign matter.

P.V.C. filter cloth for anode bags and filter presses, P.V.C. aprons, P.V.C. coated gloves and boots are other applications for P.V.C. in this industry.

The food and beverage industry

Non-toxic grades of rigid and plasticized P.V.C. are used for table tops in many food-processing factories, for instance for mixed pickles. Baskets on conveyors used in canning plant are nowadays made from rigid P.V.C.—in this particular case they last considerably longer than baskets made from galvanized iron—they are also much easier to clean.

Refrigerators (Fig. XVII/33) and food display cabinets (Fig. XVII/34) are lined both on the inside and outside with rigid P.V.C.

panels and linings; the floors of some food processing factories, filling stations and bottling rooms are frequently laid in plasticized P.V.C. (welded) to facilitate cleaning and prevent seepage of the waste liquids, etc., through concrete floors.

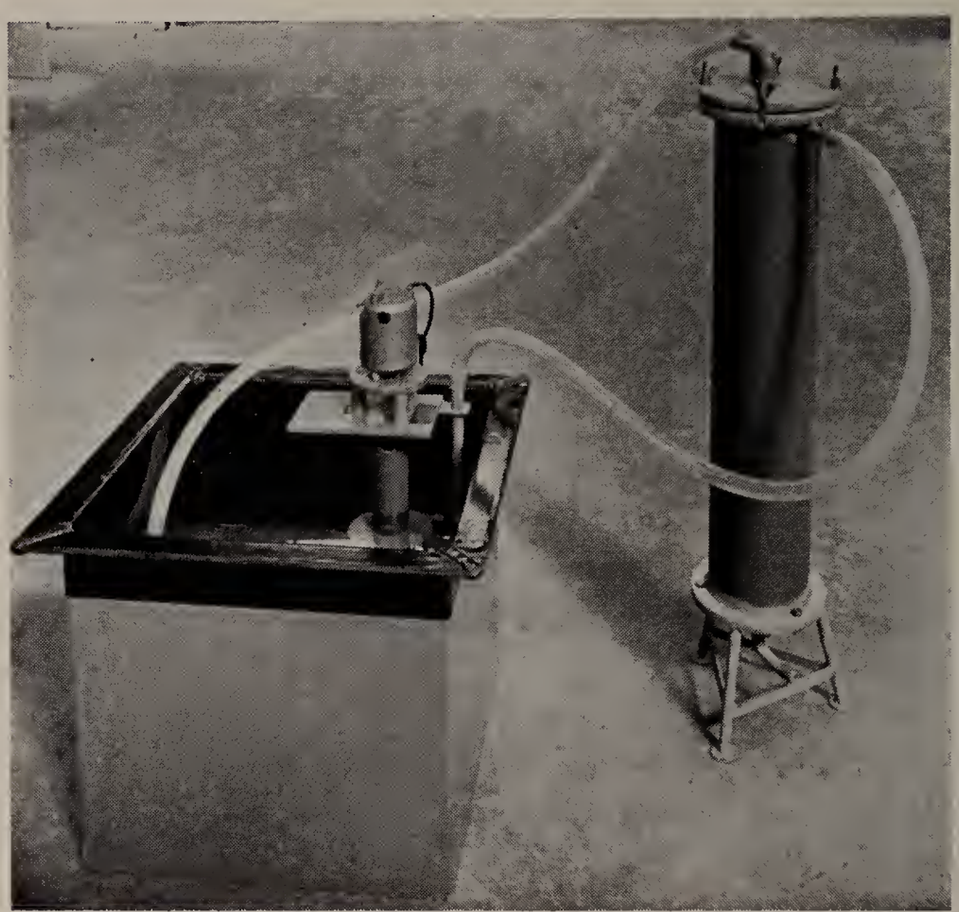

FIG. XVII/32.—P.V.C. filter unit with P.V.C. pump for plating solutions.

German and French wine bottlers use filling machines which are built to a large extent from rigid P.V.C. Huge P.V.C. lined vats are used in France and Algeria to store wine and vinegar. A 60,000 gallon vinegar tank is shown in Fig. XVII/35.

American dairies use crystal clear P.V.C. tubing (plasticized) on milking machines. This type of tubing can be sterilized by steam and is apparently acceptable to American health authorities.

Marine applications

P.V.C. in rigid and plasticized form has found many uses in Naval architecture. P.V.C. floors and P.V.C. upholstery replace linoleum, leather and rubber, not only for economical reasons—they have the further advantage of being non-inflammable and for the same reason P.V.C. fabrics, for instance curtains, are fitted to most French ocean liners. It is reported that Insurance Companies quote considerably lower rates in cases where P.V.C. floors and P.V.C. fabrics are fitted.

Other applications for P.V.C. on board ships are cables and wires,

linings for large cold chambers, wall panelling, and on a small scale pipes for brine solutions.

P.V.C. louvres (Figs. XVII/36 and XVII/37) have been installed on board of ships for several reasons. They are not prone to corrosion like metal louvres and they do not need maintenance. They also assist in reducing the noise caused by vibration of the duct system.

A most interesting application has been reported from the U.S.A. (*5*) American warships have recently been fitted with extensive P.V.C. pipe installations on their decks. These pipes are fitted with spray nozzles and are used to wash the decks and upper-structure of the ships with a special solution which decontaminates these surfaces quickly from the effects of a fall-out following an attack by atomic bombs. High impact P.V.C. is used for these pipes.

FIG. XVII/33.—Refrigerator lined on the inside and outside with rigid P.V.C. sheet.

Metallurgical industries

Pickling Equipment.

The removal of nitrous acid vapours and other obnoxious fumes developed during metal pickling processes is a difficult problem.

The resulting fumes (NO and NO_2) are not only highly irritating but they may also cause fatal accidents in severe cases.

FIG. XVII/34.—Refrigerated food display cabinets lined and faced with rigid P.V.C. panels.

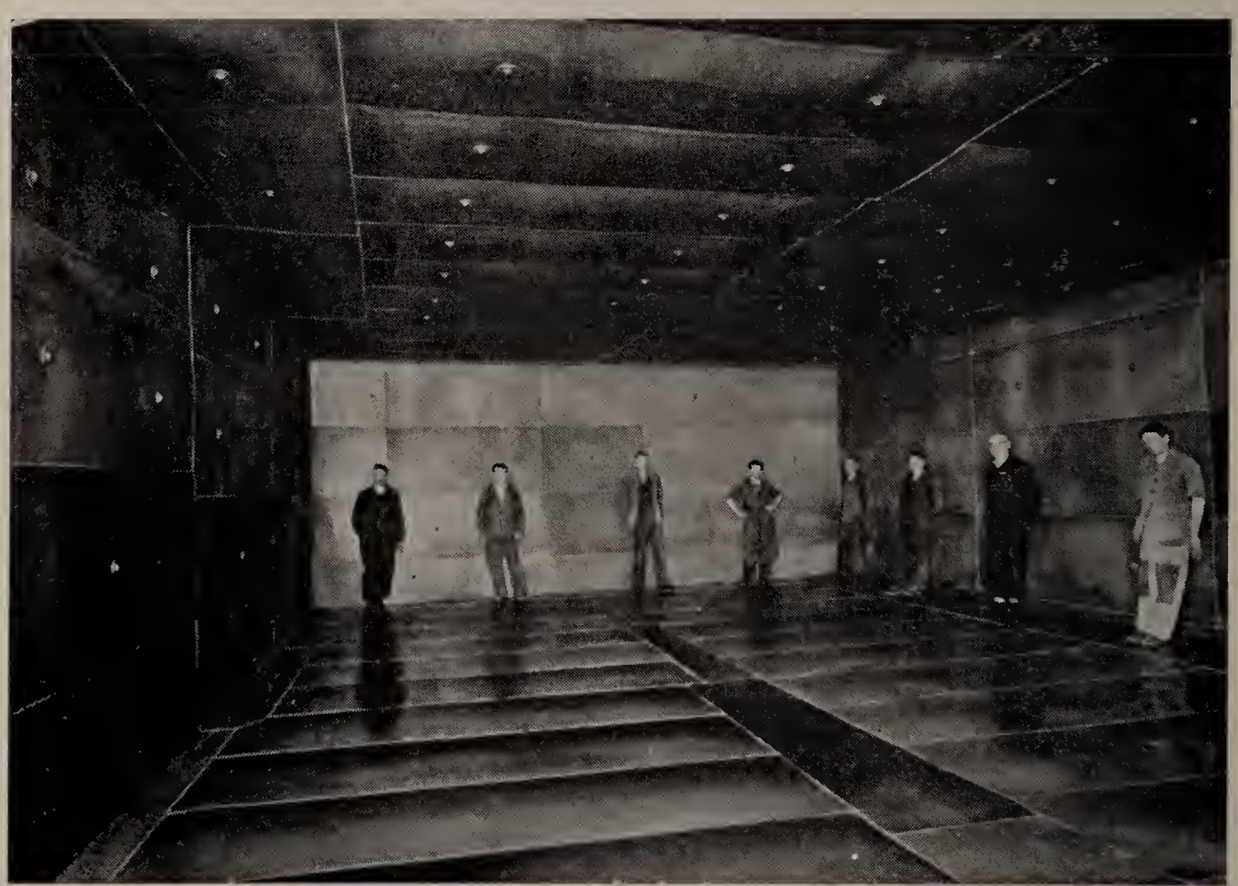

FIG. XVII/35.—Large concrete vat lined with rigid P.V.C., for the storage of vinegar (60,000 gallons capacity.)

Health inspectors and Welfare Departments insist, therefore, that these gases are effectively removed and the time has passed when these fumes were allowed to be blown off into the surrounding atmosphere without neutralization.

Both NO and NO_2 are difficult to absorb—passing the fumes through water is not very effective—and washing of the fumes with alkaline solution removes only a certain percentage of these highly dangerous gases.

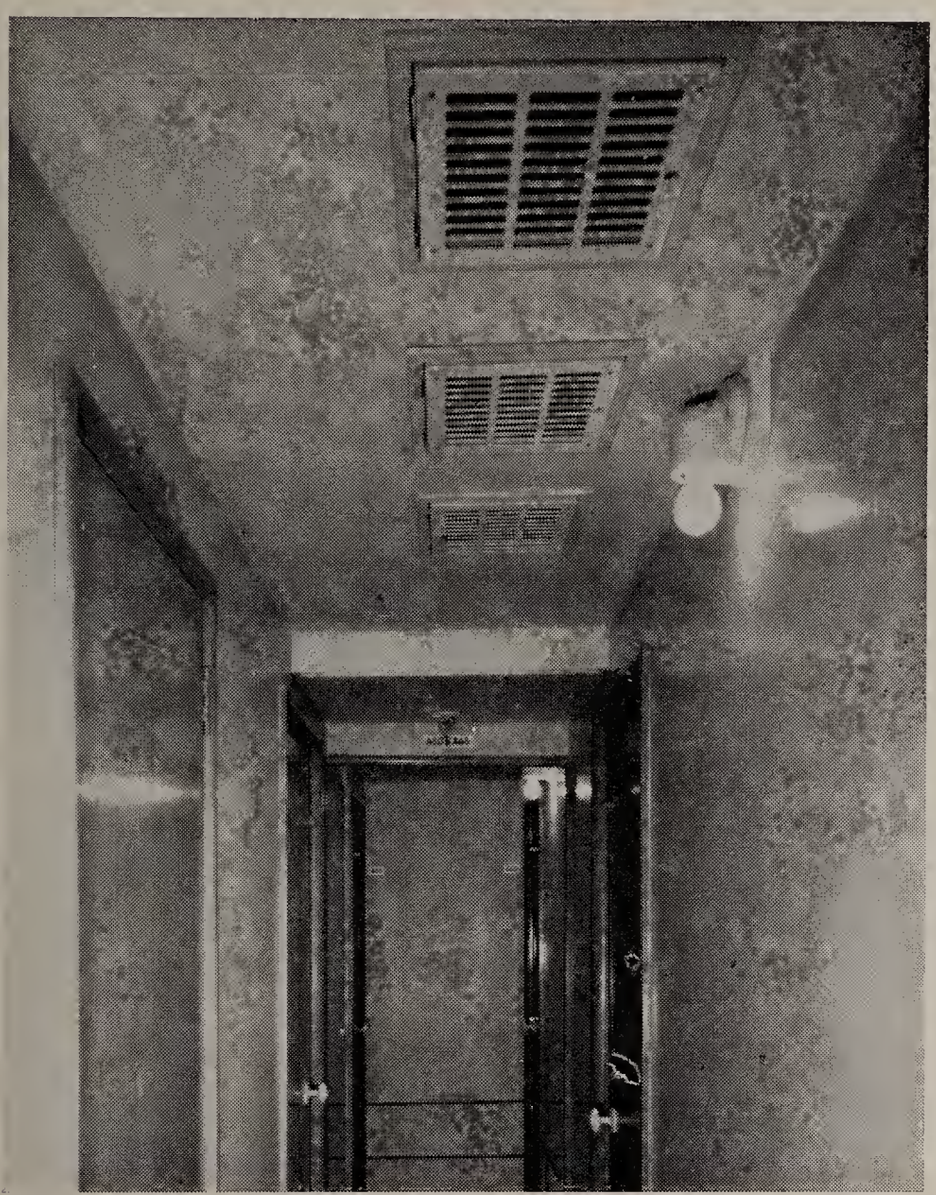

FIG. XVII/36.—Rigid P.V.C. deckhead ventilation slats on board R.M.S. *Sylvania.*

The Colasit process, invented in Switzerland, provided the first solution to this problem. It is patented in many countries; British Patent No. 693,775 covers the patent rights in the United Kingdom.

This process employs activated carbon of specified porosity for the absorption of nitric acid vapours; in addition ammonia and water are sprayed into the duct system with the result that a large percentage of the gases is effectively neutralized by ammonia vapours.

A sensitive photo-cell is incorporated which opens the valve of the ammonia container whenever yellowish or brown fumes pass the photo-cell and interfere with the light transmission of the bulb directed towards the photo-cell. The incorporation of this photo-cell increases the economy of the plant by saving ammonia.

Fig. XVII/38 shows details of the colasit plant. Fig. XVII/39 shows a schematic diagram of it.

At least three different sizes of colasit cabinets are supplied as standard items; the same system of fume removal can also be used for absorption towers.

FIG. XVII/37.—Rigid P.V.C. louvres on board the S.S. *Mauretania.*

Another type of pickling cabinet, which also uses ammonia as neutralizing agent, is shown in Fig. XVII/40. The ammonia control of this unit is not automatically controlled and activated carbon is not employed for the final fume removal.

Pickling on a very much larger scale is undertaken in steel works and wire mills. The use of P.V.C. on such plant is, however, limited, as accidental dropping of the heavy sheets or coils would destroy the P.V.C. fabrications at once.

The large pickling vats in steel works are brick lined with an impervious membrane of plasticized P.V.C. inserted between the outer and inner brick shell (Fig. XVII/41). Some of the duct work for the removal

of the hydrochloric acid fumes has been fabricated in rigid P.V.C. Other P.V.C. items in steel pickling plant are fume stacks and chimneys.

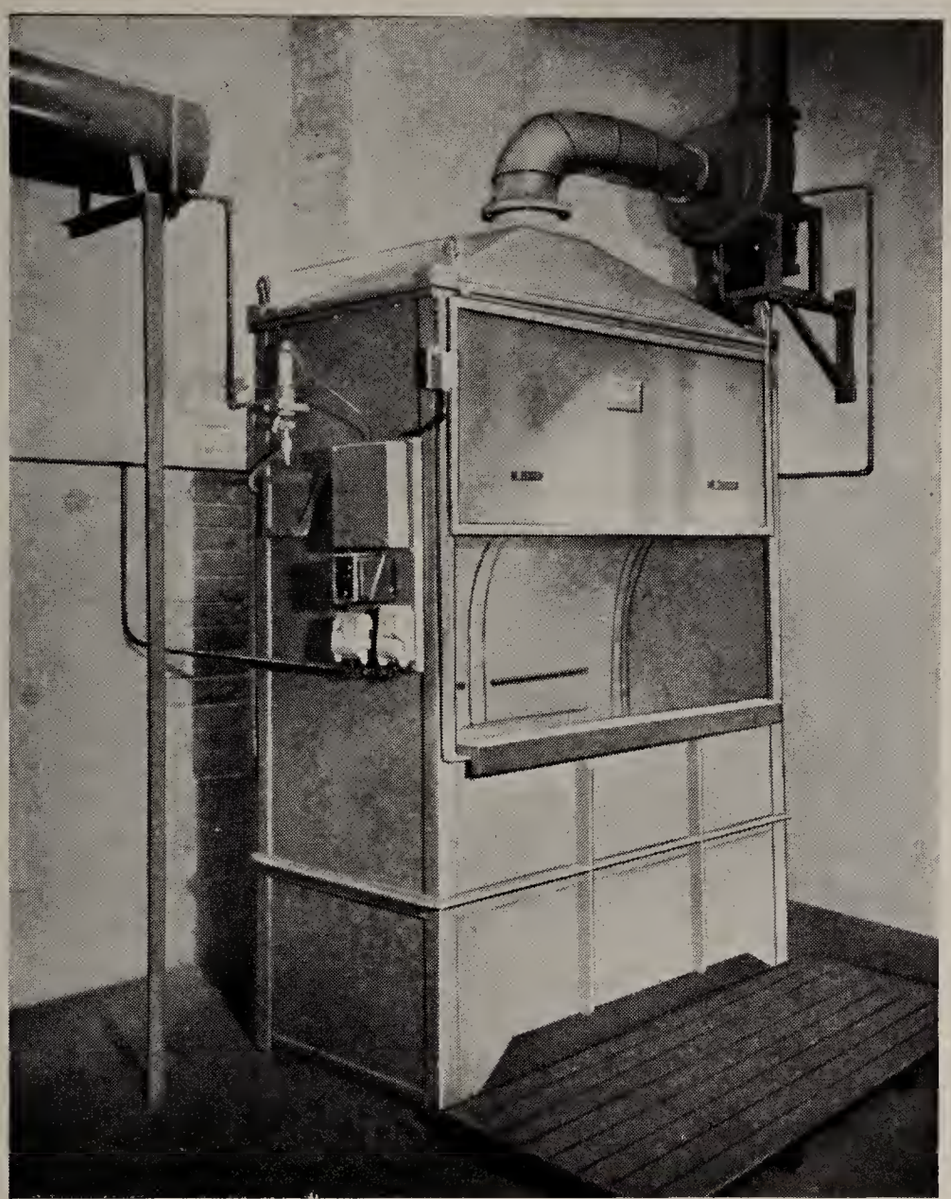

FIG. XVII/38—Colasit pickling plant fabricated in rigid P.V.C.

Mining

The mining industry offers a wide scope for applications of P.V.C., both plasticized and unplasticized.

The most important application of P.V.C. in this industry are flame-resistant conveyor belts for coal mines. More than 75 fires on underground conveyors occurred in British Coal Mines between 1940 and 1950; but none of these was as serious as the fire at the Creswell Colliery in 1950 when more than 80 miners died following a fire caused by rubberized conveyor belts.

There are various reasons for a rubber belt to catch fire, for instance, friction caused by folding or slipping of a belt with the drums still rotating; rollers or idlers may overheat and set fire to coal dust and this may in turn set the rubber belt on fire.

Skinner (7) discussed this problem extensively and described the development work which eventually led to a flameproof conveyor belting based on plasticized P.V.C. This new type of belting is now gradually replacing the rubber belting hitherto used in British Coal Mines. More than 10,000 tons of P.V.C. per annum are today used for the production of these belts in the United Kingdom. Little information is available concerning the use of such conveyor belts in other countries.

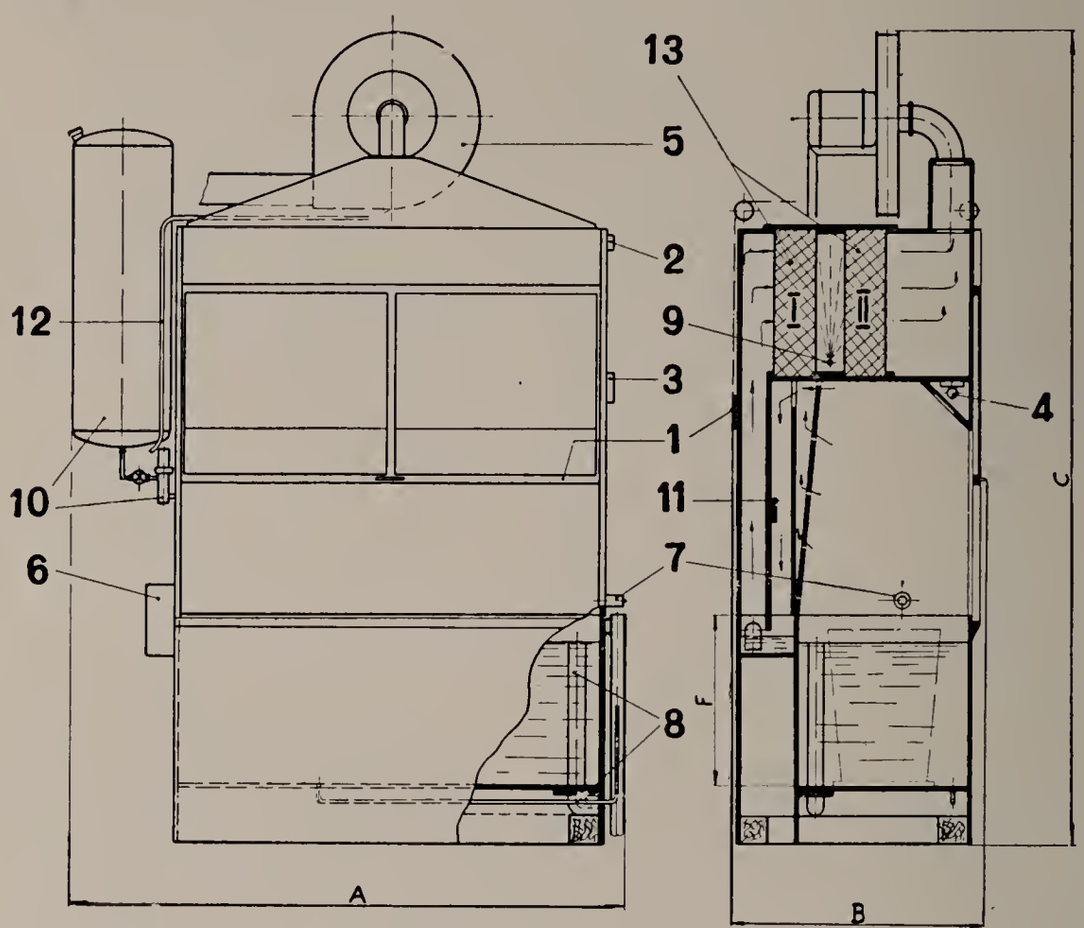

FIG. XVII/39.—Schematic diagram of a Colasit plant.

1. Counterbalanced window.
2. Electric switch to mains.
3. Secondary switch with thermal relay.
4. Fluorescent light.
5. Motorised fan.
6. Photo-electric cell for ammonia supply.
7. Light bulb.
8. Water supply and drainage.
9. Spray unit for filter.
10. Ammonia reservoir with stopcock, filter and electro-magnetic dosing equipment.
11. Ammonia supply.
12. Test pipe for waste gases.
13. Filter elements (activated charcoal).

American and Canadian mines have recently taken up the installation of rigid, shock-resistant P.V.C. piping on a large scale. Ease of assembly, light weight, excellent corrosion-resistant properties are the main reasons for this trend. The older types of rigid P.V.C. are too brittle for rough underground work.

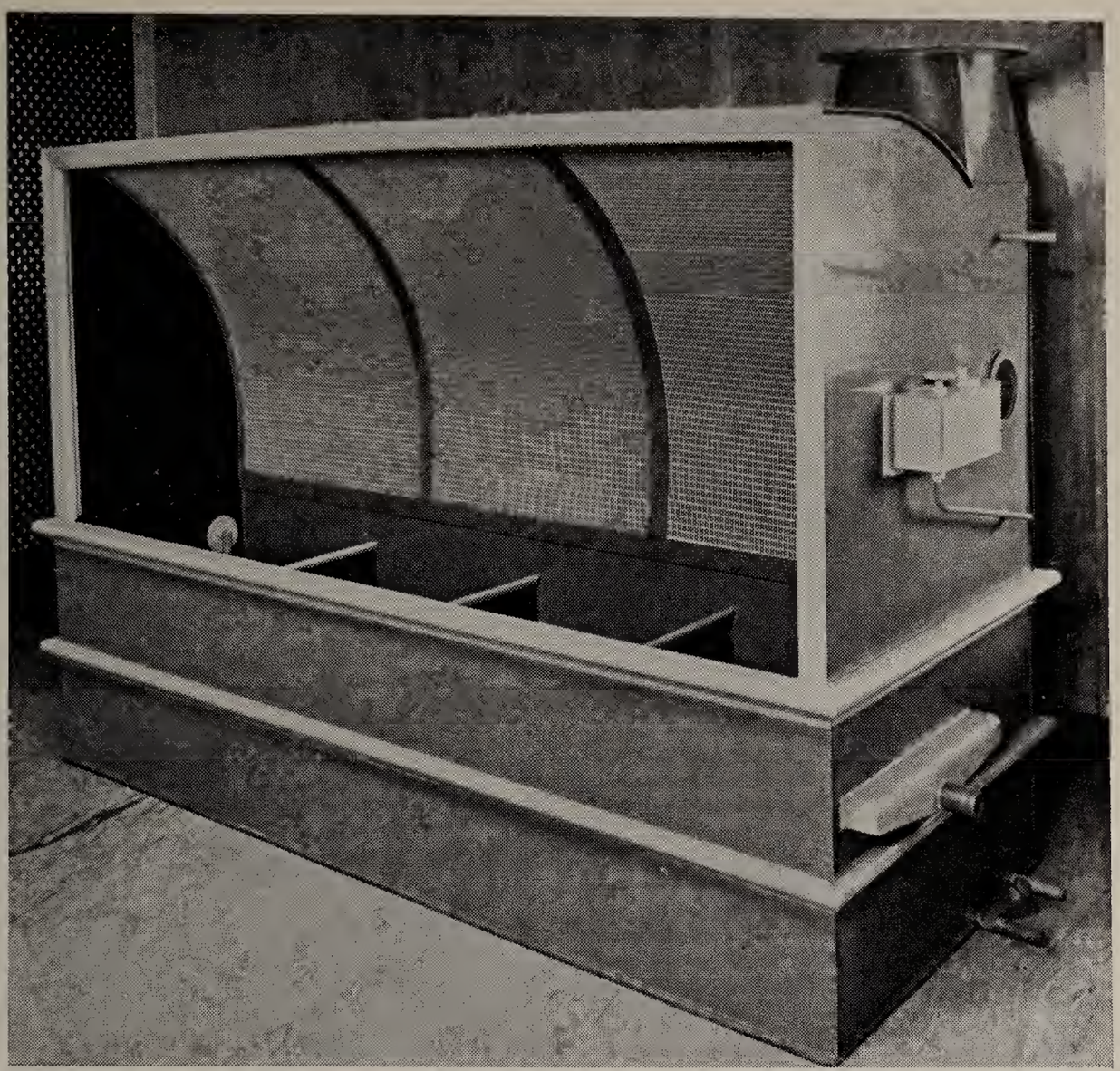

FIG. XVII/40.—Another type of P.V.C. pickling cabinet with ammonia absorber.

Weather ducts in P.V.C. are used in Germany and France. More than 300 miles of such ducts have been installed in Germany up to 1957.

South African mines employ vibratory steel shutes covered with plasticized P.V.C. Ease of installation and better wear are claimed compared with rubber lined shutes previously used.

Another important use for rigid P.V.C. is lining of couplings in mine lifts. The friction coefficient of rigid P.V.C. (0·5–0·6) is sufficient to stop steel ropes and cables running over these linings from slipping even if these ropes or cables get wet or immersed in oil. The wear and tear of these linings is low and so is the wear and tear on the ropes.

In shafts with insufficient ventilation, however, the temperature may be much higher and exceed permissible limits; P.V.C. liners should not be used in such cases.

Protective clothing, miners' helmets, shoes and boots are other applications for P.V.C. in mines.

German mines install mats fabricated from rigid P.V.C. strips and plasticized P.V.C. supports in the wash room for miners. The use of

these mats has considerably reduced the occurrence of eczema (athlete's foot).

The motor car industry

One of the larger users of P.V.C. is the motor car industry. A considerable amount of P.V.C. can be found in every modern car.

It was suggested some years ago that the American motor car industry could be a very important consumer of P.V.C.; extensive market surveys were made to find large scale uses for this material and a possible

FIG. XVII/41.—Four steel tanks internally lined with plasticized P.V.C. acting as a membrane. Two tanks are brick-lined, the two other tanks have wooden battens for protection of the P.V.C. linings.

consumption of roughly 7 lb. per car was predicted; this at a production rate of 5 to 6 million cars a year would present an outlet for approximately 30,000 tons per year for this application alone. Recent reports from America indicate that this aim has now been achieved. The facia board in many cars and the frames around windscreens are now made from rigid or semi-rigid P.V.C. (see Fig. XVII/42); ignition cables and petrol tubing are made from oil-and-petrol-resistant plasticized P.V.C. compounds, but by far the largest use of P.V.C. in American cars is for covering springs in the upholstery to prevent squeaking. There is also a large tonnage of P.V.C. going into P.V.C. leather-cloth for upholstery and interior linings of cars.

The petrol tubing on motor cycles and petrol engines is, in the majority of cases, made from plasticized oil-and-petrol-resistant P.V.C. It should, however, be mentioned that most P.V.C. compounds are unsuitable for these purposes; the plasticizers are partly leached out and the tubing soon hardens up and becomes brittle.

FIG. XVII/42.—Coach work panelling in rigid P.V.C. Seat backs and side panels in red P.V.C. Lining underneath luggage racks in white P.V.C.

The photographic industry

A wide variety of equipment for the photographic industry, mainly for developing and fixing of films or slides, can be produced in rigid P.V.C. Photographic trays in standard sizes are deep drawn or vacuum formed from $\frac{1}{32}$ in. material; they should be sufficiently rigid, especially in larger sizes, to prevent distortion or buckling when taken from one location to another. P.V.C. developing tanks (Fig. XVII/43) for ordinary photographic films and for colour film are standard items in this industry.

Most plant used in the processing of colour films is nowadays fabricated from rigid P.V.C. which is ideally suited for this purpose. (Contamination by traces of metals may cause serious colour changes in the film.) Fig. XVII/44 shows a complete processing plant with tanks, P.V.C. pipe lines and pumps. Details of a similar plant were given by Hawerkamp (*2*).

Printing

Rigid, unplasticized P.V.C. foil is growing in importance as a material for printing blocks. Foils with different degrees of hardness (45–100 shore) are available for offset printing and rotary printing.

P.V.C. foil is sufficiently flexible to overcome the difficulties of other materials which warp or distort when they are put on the cylinders of rotary printing machines; reproduction is excellent and exact, shrinkage reduced to a minimum. It is a further advantage of P.V.C. foil that it can be used again for new blocks after heating and softening.

P.V.C. blocks wear very little in use and up to 1,000,000 prints can be taken from one and the same block.

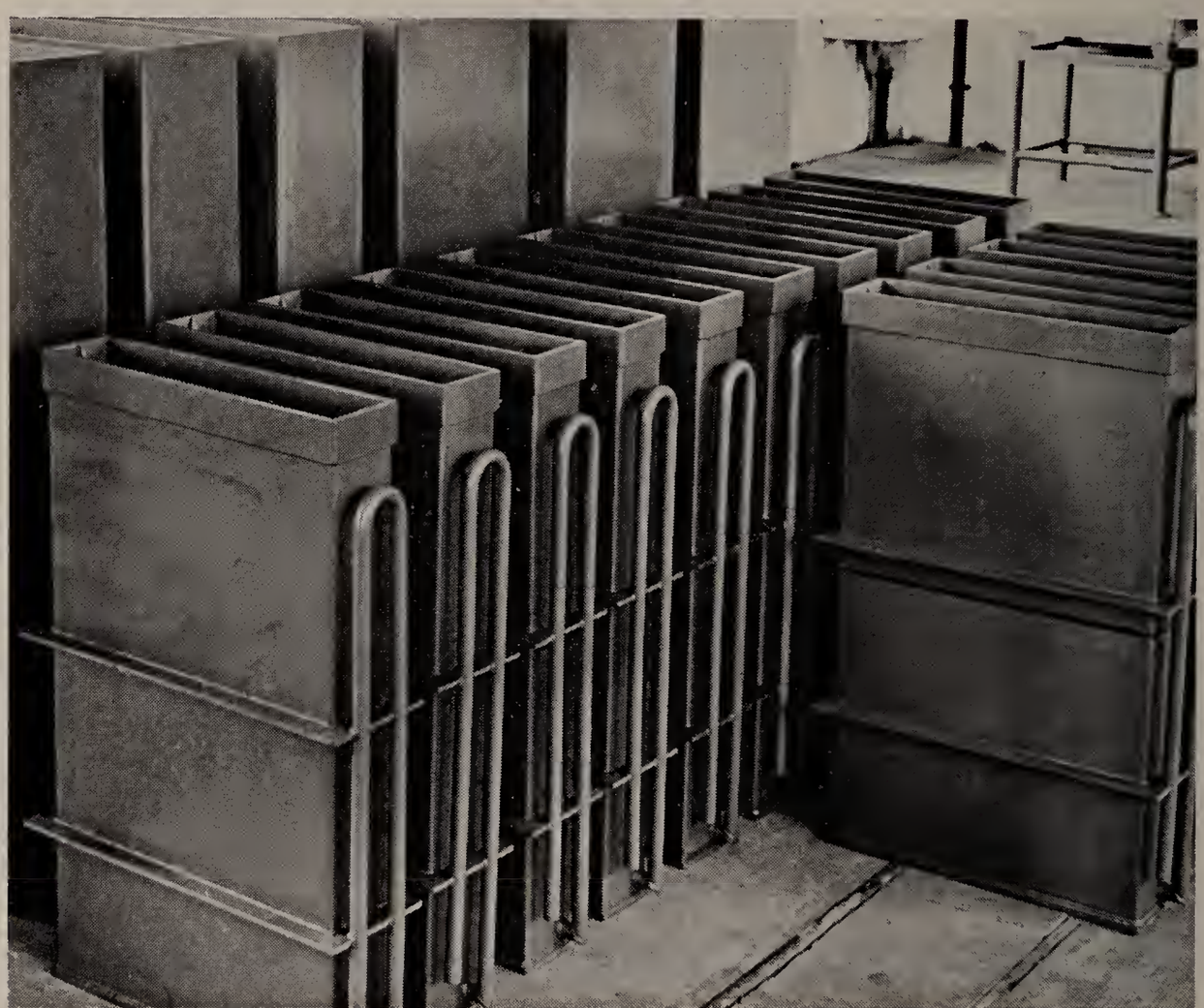

FIG. XVII/43.—A set of rigid P.V.C. developing tanks for colour films.

The pulp and paper industry

The pulp and paper industry has its own corrosion problems. Pulp processing is a very wet process and steam containing sulphur and gases is escaping in many places. Canadian and American plants use to a large extent high impact P.V.C. tubing and pipes and they also line bleach towers for chlorine dioxide with plasticized P.V.C.

Surgical applications

In general there is very little use for P.V.C. in surgery. Rigid

unplasticized P.V.C. has been used occasionally for instrument trays and the like, although the material has no particular merits in this instance as it cannot be sterilized by steam.

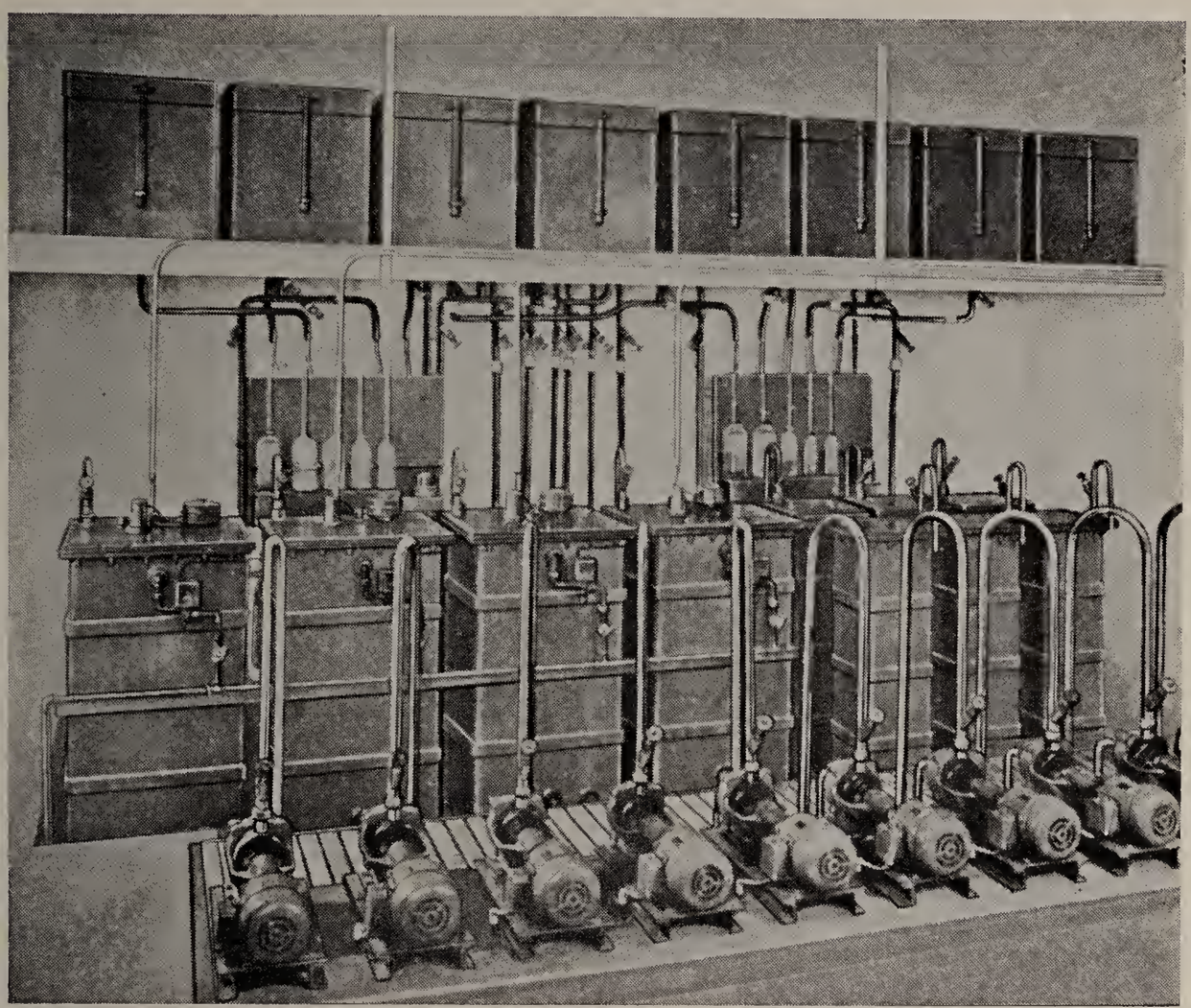

FIG. XVII/44.—Fully automatic plant for the developing of colour films entirely fabricated from rigid P.V.C.

Plasticized P.V.C. is used in a few countries for intravenous tubing for blood transfusions; great care should be taken to select a suitable compound (free from harmful plasticizers and stabilizers).

There is a limited use for plasticized P.V.C. in hospitals in the form of oxygen tents and incubator boxes; for this purpose transparent, plasticized P.V.C. sheets are made up into the desired shapes by high-frequency welding.

Tanning

Fulling troughs, fulling drums, (Fig. XVII/45), hide-dressers trestles and stretching tables are frequently lined with rigid P.V.C.

Miscellaneous applications

Fig. XVII/46 shows a rail tanker used for carrying caustic alkali solutions. Its outside is lined with coloured, plasticized P.V.C. sheet which effectively protects the surface and makes repainting unnecessary.

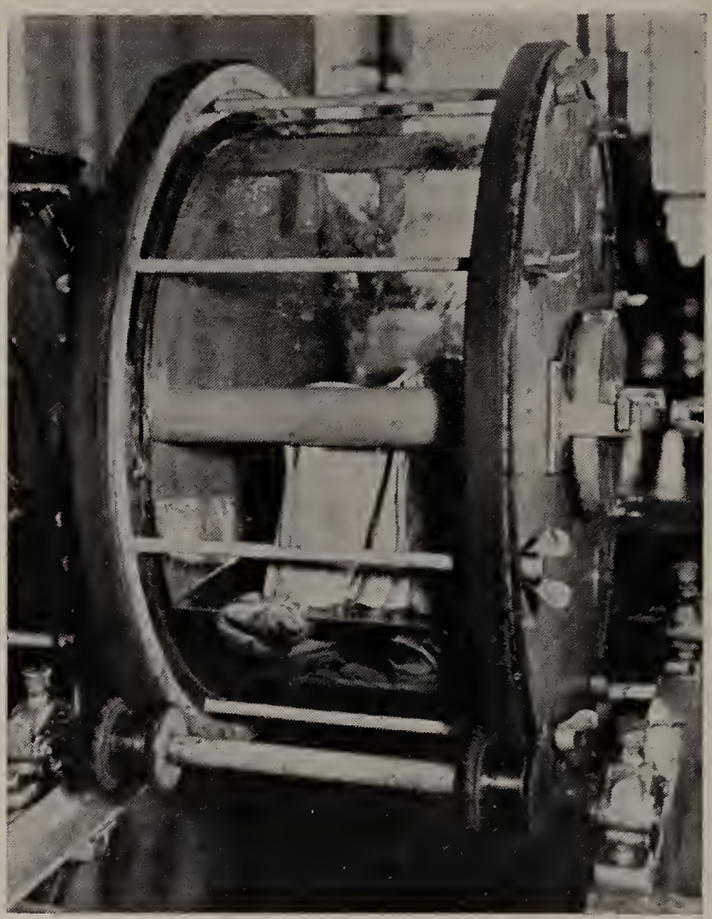

FIG. XVII/45.—Fulling drum for tanning. The inside of the drum is covered with rigid P.V.C., the cylindrical shell is manufactured from transparent P.V.C.

FIG. XVII/46.—Rail tanker for caustic alkali solutions lined on the outside with plasticized P.V.C.

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CHAPTER XVIII

TRAINING OF WELDERS

IT USUALLY takes a considerable time before new techniques and methods are recognized and adopted by industry. It is, therefore, not astonishing that technical schools and training establishments do not offer training courses before such recognition has officially taken place. On the other hand, it is rather difficult to promote new methods if they cannot be properly taught. This shortcoming has been one of the reasons why the welding and fabrication of polyvinyl chloride has taken a considerable time. The Germans soon came to realize that their attempts to introduce polyvinyl chloride in place of metals were bound to fail unless the industry provided proper training facilities, and they started welding and fabrication courses for plastic materials, and in particular, for rigid polyvinyl chloride in 1939 at their training establishment for metal welders at Halle a/d Saale. For a long time this training establishment was the only one of its kind. It was sponsored by German firms who produced welding equipment or weldable materials. The plastic welding courses, however, were sponsored mainly by the manufacturers of the plastic raw materials.

After the division of Germany into four independent Zones in 1945, Halle a/d Saale became part of the Russian Zone. In 1949 a new welding school was opened in Aachen, connected to the Kunststoff-Institut, which is managed by the Technische Hochschule, Aachen. In 1951 a further welding course was opened at the Technische Hochschule, Darmstadt. Details of the welding courses offered by both these training establishments are given at the end of this chapter.

It is rather unfortunate that independent training establishments for metal welders have not thought it worth while to include welding and fabrication courses for thermoplastic materials in their programmes. Quite recently, a few of the technical colleges in Great Britain have started to offer a practical course for plastic plumbers, which includes some relatively short tuition in welding as far as the joining of pipes is concerned. It is hoped that further courses will be added by colleges to cover the welding and fabrication of plastics in its entirety.

Apart from these official training courses, a few firms producing welding equipment offer training courses in their works, but these will probably come to an end once independent courses become available.

The instruction of trainees in independent schools is, however, preferable insofar as the latest techniques can be taught unbiased, and a stricter discipline can be applied than in schools supported by individual firms.

A list is given below of the various training establishments and training courses available in different countries.

England

TRAINING COURSES FOR PLUMBERS IN PLASTICS

Borough Polytechnic: Borough Road, London, S.E.1.
College of Technology: Building Department, Osborne Street Annexe, Kingston-upon-Hull.
College of Technology: Howard Street, Rotherham.
Technical College: Barking Road, East Ham, London, E.6.
Derby and District College of Technology: Civil Engineering and Building Dept., Normanton Road, Derby.
Erith Technical College: Erith Road, Belvedere, Kent.
North West Kent College of Technology: Miskin Road, Dartford, Kent.
Widnes College of Further Education: Victoria Square, Widnes, Lancs.
The Woolwich Polytechnic: Building Department, Woolwich, London, S.E.18.

France

École Nationale Professionnelle, Oyonnax (Ain). Welding Course for Thermoplastic Materials.

Germany

There are at the present time two training establishments offering a training course for plastic welders, one in Aachen and the other in Darmstadt.

The Institut für Kuntststoffverarbeitung in Industrie und Handwerk, Jülicher Strasse 336, Aachen, attached to the Rheinisch-Westfälische Technische Hochschule, Aachen, runs three-weekly courses for the working and fabrication of thermoplastic materials. The Institut also runs courses from time to time in other towns: Essen, Frankfurt/Main, Hamburg, Nürnberg and Stuttgart.

The courses offered at the Staedtische Ingenieurschule, Darmstadt, Eschollbruecker Strasse 27, are similar and an extract of the syllabus is shown below.

These courses are held for the benefit of semi-skilled and skilled operators working in the metal and plastics industries. A practical knowledge of the working of metals is desirable. Further courses are

offered for foremen and engineers. They have to serve two purposes, i.e. apart from theoretical discussions, thorough instruction is given in the forming, welding and cementing of thermoplastic materials. Details concerning the technique of lining tanks and containers with polyvinyl chloride and poly isobutylene are given. The working of plasticized polyvinyl chloride, polythene and acrylic materials is also taught.

A certificate of proficiency is given to trainees who have successfully completed one of the courses. The certificate is authorized by the German Institute of Welding. In cases where trainees have undergone a more extensive training, reference is made to this effect on the certificate.

The ordinary course extends over three weeks, but in the case of completely unskilled pupils, this period will be extended as required. The school is open from Monday to Friday from 8.15 to 12.30 and from 1.30 to 5.0, and on Saturday from 8.15 to 12.30. Courses are not held regularly, but an announcement is made from time to time in the technical press.

The fee for a welding course of three weeks' duration is 240.–DM and for each additional week a charge of 80.–DM is made. If several pupils attend from the same firm, a reduction is made in the fees.

For tuition on special subjects a special fee is charged, based on the number of trainees for this particular subject and varying between 10.– and 20.–DM. per day.

Syllabus for a Three Weeks' Welding Course in the Welding and Fabrication of Thermoplastic Materials.

First Week: Introduction and work dealing with basic principles.

1st Day—*Theoretical part:*

Lecture: General review of the more important plastic materials, their properties and workability.

Practical part:

Inspection of the training establishment; explanation and demonstration of the various tools required; manipulation of welding torch; deposition of single-layer welds.

2nd Day—*Practical part:*

Deposition of single-layer welds; hot forming of comparatively simple parts; bending and folding of foil and sheet.

3rd Day—*Theoretical part:*

Lecture: The various types of welds suitable for plastic materials.

Practical part:

Deposition of butt-welds (chamfered edges); making of sleeves up to 6 in. diameter; cementing.

4th Day—*Practical part:*
Deposition of butt-welds (double chamfer); bending of pipes; manufacture of flanges; hot forming by presses, deep drawing and blowing.

5th Day—*Practical part:*
Deposition of fillet welds; manufacture of an expansion piece; turning, shaping, drilling and milling.

6th Day—*Practical part:*
Section welding; covering of wood and steel with pipes; manufacture of pipe sections exceeding 6 in. in diameter. Resumé of the weekly progress.

Second Week: The trainee commences the fabrication of more complicated pieces from a drawing or blueprint.

1st Day—*Theoretical part:*
Lecture: The planning and fitting of pipelines.
Practical part:
Cementing, welding and fitting of pipe sections and intersections.

2nd Day—*Practical part:*
Hot forming of more complicated parts; manufacture of sleeves and work in Astralon.

3rd Day—*Practical part:*
Preparation of tensile specimens, V and X preparation; covering of a steel roller with polyvinyl chloride by blowing.

4th Day—*Theoretical part and Practical part:*
Lecture, demonstrations and practical work concerning the fabrication of acrylic materials.

5th Day—*Theoretical part:*
Lecture: Review of the applications of thermoplastic materials and their use in the chemical industry and in the manufacture of chemical equipment (with slides).

6th Day—*Practical part:*
Preparation of tensile specimens, V and X preparation; Review of the work of the past week.

Third Week:

1st Day—*Practical part:*
Preparation of a prototype according to a drawing.

2nd Day—*Practical part:*
Preparation of a prototype according to a drawing.

3rd Day—*Practical part:*
Preparation of a prototype according to a drawing; preparation of tensile specimens, V and X preparation.

4th Day—*Practical part:*
Lining of a container with polyvinyl chloride foil.
Theoretical part:
Lecture, demonstrations and practical work.

5th Day—*Practical part:*
Lining of a container with poly isobutylene (Oppanol ORG).
Theoretical part:
Lecture, demonstration and practical work.

6th Day—Final examination (theory) and practical examination of the work done during the course.

An alternative welding course for lining of tanks and containers with thermoplastic materials is also available. It is assumed that the student has sufficient knowledge of fabrication of rigid polyvinyl chloride, acquired at the training establishments at Aachen or Darmstadt. Alternatively, he should have practical experience in this field acquired over a period of at least 10–12 months.

Apart from theoretical discussions, basic practical tuition is offered for the cementing and welding of linings for steel, timber and concrete; the flame-spraying of thermoplastic powders is shown. This course should be followed up by a fortnight's course at one of the various firms who specialize in the lining of containers. Here again a certificate of proficiency is offered.

The course lasts for two weeks and a third week can be added if required. The charge is 120.–DM., and a further 60.–DM. is charged for each additional week.

Syllabus for a Course for the lining with Thermoplastic Materials

First Week:

1st Day—*Theoretical part:*
Lecture: Review of the various materials used and their application.
Suggestions for the installation of a workshop dealing with linings.
Demonstration and explanation of the tools to be used.
Practical part:
Welding of polyvinyl chloride strips.

2nd Day—*Theoretical part:*
Preparation of the materials to be lined. Theory and use of

cements. Cementing of polyvinyl chloride and poly isobutylene sheet. Development and patterns.

Practical part:

Preparation of surfaces to be lined (timber, concrete). Application of the cement and of polyvinyl chloride foil. Welding of polyvinyl chloride strips.

3rd Day—*Theoretical part:*

Lining of containers with polyvinyl chloride foil.

Practical part:

Welding of polyvinyl chloride linings on steel, timber and concrete. Testing of the lining by means of a spark tester. Welding of a covering strip over welds. Preparation for the coating of profiles in steel, wood. Application of the cement and subsequently of polyvinyl chloride foil.

4th Day—*Practical part:*

Lining of the various profiles prepared on the previous day. Welding, testing with the spark tester and over-welding with a covering strip. Preparation of relatively large objects. Development work, pattern work.

Lining of relatively large objects. Welding, testing, etc.

5th Day—*Practical part:*

Lining of relatively large objects. Welding, testing, etc.

6th Day—*Theoretical part:*

Lecture: Polyvinyl chloride, poly isobutylene and polythene—their properties and applications. The lining of tanks and containers with poly isobutylene foil.

Review of the work carried out during the first week.

Second Week:

1st Day—*Practical part:*

Seam welds on loose poly isobutylene foil and strips. Preparation of samples on steel, timber and concrete. Application of cements and poly isobutylene foil.

2nd Day—*Practical part:*

Welding on the specimens prepared on the previous day. Preparatory work on profiles in steel and timber. Application of the cement and the poly isobutylene foil. Preparatory work on pipes to be lined inside and outside. Application of the cement.

Manufacture of poly isobutylene tubing.

3rd Day—*Practical part:*

Welding on the profiles prepared on the previous day. Application of the poly isobutylene tubing inside the pipes and welding longitudinal seams. Preparatory work on relatively large objects.

Development work and pattern work in poly isobutylene foil. Application of cement and foil.

4th Day—*Theoretical part:*
The flame-spraying of thermoplastic materials and lining employing a so-called fluidization process.
Practical part:
Lining of larger objects and welding of final seams. Preparatory work on steel sheets, flanges, covers and other small parts to be lined afterwards by a flame-spraying or sintering (fluidization) process.

5th Day—*Practical part:*
Lining of the various parts prepared on the previous day by flame-spraying or sintering.

6th Day—Oral examination. Review of the various specimens and samples.

Eastern Germany (D.D.R.)

The training of fabricators in thermoplastic materials and in particular the training of welders, in the German Democratic Republic, follows rather interesting lines.

According to Schrader (*1*) most semi-finished P.V.C. products in that country are used in the building industry; some considerable trouble was encountered due to bad workmanship in the earlier stages and a Government decree, dated 23rd January, 1956, was issued to lay down rules for installation work in P.V.C. According to this decree, installations of P.V.C., such as guttering, linings, pipelines (up to 7 p.s.i.), can now only be installed by craftsmen who have a certificate of proficiency in the working of P.V.C. Such a certificate can either be obtained after passing through a course at the Zentralinstitut für Schweisstechnik der DDR. Halle (Z.I.S. for short) or from the Institut für Technik und Prüfwesen, Berlin-Wilhelmsruh. Any workman who has passed through either of these Institutes or through a training school licensed by Z.I.S., is entitled to a basic certificate. Certificates issued before January 1st, 1956, are also recognized. Welders or craftsmen who have not passed through a recognized training course, but who have at least one year's experience in the working of P.V.C., can register for an examination; if they are successful they also obtain the basic certificate. The examination consists of an oral test dealing with theoretical and practical points encountered in the use of P.V.C. Apart from the oral examination the candidate has to carry out seven practical tests, details of which are given below.

Basic certificate (*Grundprüfung*)

Scope: Fabrication and welding of P.V.C. for plumbing work in the

building industry, including installation of pipelines for pressures of not more than 7 p.s.i.

Test No. 1. Deposition of a 'V' type weld on P.V.C. sheet 6 in. long. Re-welding at the root. The deposit is not dressed afterwards. Three test specimens are cut. The following points are considered in particular: neatness, tensile strength (a strength of at least 50 per cent. of that of the parent material is required).

Test No. 2. Welding of a double butt-weld on $\frac{1}{4}$ in. P.V.C. sheet 6 in. long. Here, again, the weld is not dressed afterwards. Three specimens are cut. The following points are considered in particular: neatness, tensile strength (a strength of at least 50 per cent. of that of the parent material is required).

Test No. 3. Preparation of a bell and spiggot joint by heating the pipe over an open flame from 2 in. bore $\times$ $\frac{1}{16}$ in. wall P.V.C. pipe, 18 in. long. Marks are accorded for keeping to tolerances and neat appearance.

Test No. 4. Preparation of a T-piece with outlet from P.V.C. pipes, 2 in. bore $\times$ $\frac{1}{16}$ in. wall, 16 in. long and $1\frac{3}{4}$ in. bore $\times$ $\frac{1}{16}$ in. wall, 8 in. long. Marks are given for keeping to tolerances and neat appearance.

Test No. 5. Preparation of a bend in P.V.C. pipe $1\frac{3}{4}$ in. bore $\times$ $\frac{1}{16}$ in. wall, 20 in. long. Marks are accorded for close dimensions and neat appearance.

Test No. 6. Preparation of a 90° lobster-back by cementing from P.V.C. drainage tubing 4 in. bore $\times$ $\frac{1}{32}$ in. wall, 20 in. long. Marks are accorded for close tolerances and neat appearance.

Test No. 7. Preparation of the corner part of a guttering by cementing, using P.V.C. foil $\frac{1}{32}$ in. thick and drainage tubing 4 in. bore $\times$ $\frac{1}{32}$ in. wall, 6 in. long. Marks are accorded for close tolerances and neat appearance.

The successful passing of this test for the basic certificate, however, does not give the workman the right to carry out installations involving pressures in excess of 7 p.s.i. For this he needs a further certificate of proficiency in the working of P.V.C. This certificate can be obtained by passing through a special course, followed up by an examination at Z.I.S. or in Berlin, or at any training establishment licensed by either of these. Prospective candidates must already be in possession of the basic certificate.

Before commencing this course they have to pass an entry examination and after termination of the course they have to prove in an oral examination that they have sufficient knowledge concerning the materials and the properties of P.V.C. in particular. Again seven tests have to be performed.

Proficiency certificate (*Zulassungsprüfung*).

Scope: Fabrication and welding of rigid P.V.C., including pipelines for pressures in excess of 7 p.s.i.

Test No. 1. Preparation of a bell and spiggot joint with bend and reduction piece from rigid P.V.C. tube (1 in. bore). The following points are considered in particular: close tolerances and neat appearance.

Test No. 2. Preparation of a joint of bell and spiggot type in 1 in. bore rigid P.V.C. and Kawekan pipe*. The following points are considered in particular: close tolerances and neat appearance.

Test No. 3. Preparation of a 90° lobster-back in rigid P.V.C. 4 in. bore. Points considered: accuracy and neat appearance.

Test No. 4. Preparation of a cell in $\frac{1}{8}$ in. P.V.C. with separator plate, dimensions approximately 2 in. × 4 in. × 6 in. (deep). Points considered: accuracy, neat appearance and soundness.

Test No. 5. Welding of a butt-weld ('V' joint on $\frac{5}{16}$ in. P.V.C., 6 in. long), re-welded at the root without dressing of the weld. Three test specimens are cut. Points considered: neat appearance and tensile strength, which must be at least 60 per cent. of that of the parent material.

Test No. 6. Preparation of a butt-weld ('X' type in $\frac{1}{4}$ in. thick material, 6 in. long). Preparation of three test specimens. Points considered: neat appearance, and tensile strength, which must be at least 60 per cent. of that of the parent material.

Test No. 7. Preparation of a butt-weld ('V' type) on $\frac{1}{8}$ in. thick plasticized P.V.C., 6 in. long). Points considered: neat appearance and soundness, tested by means of a spark tester.

Special training courses for plastic fabricators in the German Democratic Republic are also given; the following five courses are offered:

(1) *Basic training course* (80 hours) at Z.I.S., Halle/Saale, and at Berlin, Wilhelmsruhe. Similar courses are also offered in larger towns. The syllabus for all these courses is the same and includes basic information on heat forming and welding of P.V.C. A basic certificate is issued.

(2) *Secondary courses* (80 hours) at Z.I.S. and in Berlin for the advancement of workmen. These courses qualify the candidates for a proficiency certificate.

*Kawekan Pipes are a special type of pipes so far only produced in the D.D.R. They consist of two concentric layers of plasticized P.V.C. with a layer of textiles or wire between them. A non-toxic plasticizer is used—Kawekan pipes can, therefore, be used for water installation. They are produced by VEB Kabelwerk, Köpenick, DDR.

(3) *Courses for teachers in plastic welding* at Z.I.S., Halle. These courses are mainly intended for plastic welders who want to qualify as teachers in technical schools. The successful candidate obtains a certificate as teacher for welding and fabrication; this enables him to give instructions for courses 1 and 2.

(4) *Special courses for civil engineers, architects, works supervisors, etc.* (40 hours) at Halle. During these courses extensive discussions and demonstrations take place; up-to-date information on the use of P.V.C. and other materials in the building industry is given.

(5) *Theoretical courses for engineers, designers and foremen* (40 hours) at Z.I.S., Halle. In the course of these all the possibilities and potential uses of P.V.C. are discussed.

Holland

Courses dealing with the fabrication of thermoplastic materials, and in particular for the welding of polythene and rigid P.V.C. are held at frequent intervals by the Kunststoffen Instituut T.N.O., 134 Julianalaan, Delft.

Switzerland

Schweiz-Verein für Schweisstechnik, 95 St. Albanvorstadt, Basel.

Schweiz. Spenglermeister-und Installateurverband, Fachschule Obfelden, Zuerich.

Schweiz. Fachschule für Sanitaer-Installateure, Lehrwerkstätten, 3, Lorrainestr, Bern.

École des Métiers, 73, rue de Genève, Lausanne.

U.S.A.

The only establishment in the United States which offers welding courses at the present time is Bolta Products, a division of the General Tire and Rubber Company, Lawrence, Mass. Their training school was not established for the sole purpose of training welders but rather for a complete training programme in the working and fabrication of thermoplastic materials. It covers a five-day course and the syllabus is given below.

The training course is actually given by their Plastic Fabricators Institute.

The following subjects are covered:

1st Day—P.V.C., its history, compounding and development to date. P.V.C. as a structural material. Machining of P.V.C. Welding of P.V.C. Cementing of P.V.C. Supervised manual practice, machining, welding and cementing.

2nd Day—Calendering, laminating and pressing sheet and block stock. Testing, quality control, production control, " Red Laboratory Seal'. Heat forming—vacuum and pressure applications. Plastic Memory—precautions and useable applications. Supervised practice: Welding, vacuum and pressure forming. Extrusion of thermoplastics. Emphasis on P.V.C. pipe and rod stock. Standard, Specifications and testing. Supervised practice, welding, heat forming.

3rd Day—P.V.C. Properties: Tensile strength, elongation, creep, short and long-time burst. Moulding of thermoplastics. Aspects of P.V.C. injection, compression and transfer moulding. Pipe fittings including valves. Supervised practice—welding and heat forming. Shrink connections and cements. Shoulder bushings and cement. Comparison of the pipe installations with different kinds of fittings, actual field experience. Supervised practice, welding, shrink connections and shoulder bushings.

4th Day—P.V.C. properties, continued. Emphasis on thermal expansion, pipe installations, liners, lamination of different materials. P.V.C. Ducts—forming, cementing, welding. Welding and heat forming practice. Ventilators, exhaust fans and pumps. Calculations and fabrications. Tanks and liners.

5th Day—Plastic Pipe with emphasis on Boltaron 6200 and Boltaron 7200. Supervised practice: Welding of specimens, which will be tested in the laboratory. Final practice and discussions. Presentation of Certificates.

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CHAPTER XIX

GLOSSARY OF TERMS USED

Bond: Linkage of atoms by sharing of electrons.

Bonding: Jointing process used for plastic materials for which glues or cements are used; distinctly different from welding.

Breakdown strength (*Dielectric strength*)*:* Property of insulating materials to withstand the disruptive action of electric fields. Measured in volts/mil. or kV./cm. When breakdown occurs the material is punctured and physically changed at the point of breakdown.

Butt weld: End-to-end weld between abutting sheets.

Calendering: Method of producing plastic sheet. The calender consists of two or more heated rollers rotating in opposing directions. The material is forced between the rollers, smoothed and reduced to the correct thickness.

Catalyst: An agent which activates or promotes a chemical reaction without taking part in the reaction.

Cementing: Bonding process in which a joint is obtained by means of a cement.

Copolymer: See *Copolymerization.*

Copolymerization: The simultaneous polymerization of two or more monomers yields a product which has properties quite different from those of the individual polymers. Examples of copolymers: vinylchloride-methyl methacrylate or vinylchloride-vinylacetate, etc.

Creep: Plastic deformation occurring when a material is continuously stressed at elevated temperatures.

Diathermy: The treatment of the human body by means of capacity current heating. Metal electrodes (usually covered with insulating material) are applied to the region to be heated and H.F. current is passed through the patient.

Dielectric: Any non-conductor of electricity which is exposed to an electric field, e.g., material between plates of an electric condenser. All plastics are dielectrics in this sense.

Dielectric constant (*permittivity*)*:* The permittivity of a dielectric material is the ratio of the electric flux density in this material to that produced in a vacuum by the same electric field strength. Symbol: k.

Dielectric strength: See *Breakdown strength.*

Edge weld: Weld between outer edges of sheets at right angles to one another.

Elastic limit: Point at which a material begins to yield under stress; i.e. when the stress becomes equal or greater than the internal friction.

Elasticity: Property of a material to be deformed under an applied stress in such a manner that, on release of the stress, the deformation disappears entirely. (Elastic Deformation).

Elongation: Permanent extension of material due to stress over a standard length expressed in per cents of the original length.

$$\text{Per cent. elongation} = \frac{\text{Extension} - 100}{\text{Original gauge length}}$$

Endurance limit: The number of stress reversals applied to a test piece prior to fracture.

Extrusion (*Extruding*): Process of manufacturing using plastic flow of materials. Extruding presses for plastics have a power-driven scroll working inside a heated jacket forcing the plastic through an orifice, (die or nozzle) which corresponds to the shape to be manufactured.

Filler rod: In the so-called hot gas welding process a filler rod of the same or similar composition as the plastics to be joined is used. Its purpose is similar to that of filler rods used for gas welding of metals.

Fillet weld: Weld between sheets at right angles.

Flexural strength: The force required to break a sample which is being supported at both ends. (Breaking force applied at the centre of the sample). (Expressed in lb./sq. in.).

Flow: Property of materials to deform under load.

Friction welding: Welding process in which the heat required for the softening of plastics to be jointed is obtained by rubbing and pressing the plastic against a stationary material.

Glueing: Bonding process using a glue.

Hardness: Resistance to indentation or surface wear; resistance to permanent deformation.

Heated tool welding: Welding process for thermoplastic materials in which heated tools are used.

High frequency welding: Joining of plastics under pressure and heat, the heat being generated by high-frequency alternating fields.

High polymer: Term coined by Staudinger to distinguish high polymers with a macromolecular structure and high molecular weight from polymers having a much smaller molecular weight.

Hot gas welding: Welding process in which heated gases are used to soften and weld thermoplastic materials.

Hot plate welding: See *Heated tool welding.*

Impact strength: Property of a material to resist sudden shock. Expressed in ft. lb. (Izod test).

Lap weld: Weld between overlapping sheets.

Loss angle: In vectorial representation the angle by which the lead of the current differs from 90°. Essential for calculation of dielectric loss. Symbol: δ.

Loss factor: Product of tan. δ and dielectric constant. Physical property of a dielectric material. The loss factor is not a constant but depends on temperature and frequency.

Macromolecule: A molecule large enough to show colloidal properties.

Megacycle: Million cycles/sec.=Mc/s. Used in high-frequency terminology. Compare with: Kilocycles=thousand cycles/sec.=kc/s.

Modulus of elasticity: Characteristic constant of a material. Defined as the quotient of stress divided by elongation per unit length. Symbol: E. Dimension: lb./sq. in.

Monomer: Simplest repeating structural unit of a polymer.

Plastic flow: Property of thermoplastic materials to flow under heat and/or pressure, when the pressure exceeds a certain minimum.

Plasticizer: Organic material added to plastic compositions to render them flexible and plastic.

Polar molecules: Molecules with equal positive and negative electric charges. The centres of the charges do not coincide, i.e. dipoles are attached to the carbon atoms of a molecular chain.

Polymer: Name generally given to products resulting from polymerization.

Polymerization: Monomers polymerize when heated or aged. The molecular weight of the polymer is a multiple of that of the monomer. The monomeric molecules link up in chain form and the higher the degree of polymerization the greater the molecular weight and chain length.

Power factor: Ratio of total power loss (in watts) in a material to the product of voltage and current.

Press welding: Discontinuous welding process for limited lengths of seams by simultaneous application of heat and pressure. Pressure is exerted on the pieces to be welded by means of mechanical, hydraulic or pneumatic devices.

Seam weld: Continuous weld between overlapping sheets.

Shear or *Shearing stress:* The forces which operate in one plane of an area or in a plane parallel to it and cause the plane of the area to slide on adjacent planes.

Softening point: The temperature at which a plastic softens and becomes distorted.

Softening range: Plastics very seldom have a proper melting point and soften over a temperature range. Vinylidene chloride and polythene, however, have a proper melting point.

Specific heat: The amount of heat required to raise 1 lb. of material through 1° F. Measured in: B.Th.U./lb. °F. or Cal./Kg. °C. at 15° C. (to raise 1 kg. of material through 1° C.).

Stabilizer: Material added to a plastic in order to prevent decomposition especially when heated.

Tensile strength: Also called maximum stress or ultimate stress. The highest stress reached before the material breaks under tension. Expressed in kilograms per sq. cm. or lb. per sq. in.

$$\text{U.T.S.} = \frac{\text{Maximum load}}{\text{Original cross sectional area}}$$

Thermoplastics: Class of plastic materials which become plastic when heated and solidify again when cooled. This process can be repeated indefinitely provided no decomposition due to overheating has taken place.

Thermosetting plastics: Class of plastics which undergo a chemical change when heated. The material hardens and cannot be made plastic again by reheating.

Weld factor: Ratio of the tensile strength of a welded joint to the tensile strength of the parent material (given in per cents. of the tensile strength of the parent material).

Welding: uniting two or more materials of the same composition by means of heat and/or pressure.

CHAPTER XX

APPENDIX

CONVERSION FACTORS

Multiply	*By*	*To Obtain*
Atmosphere	29·92	Inches of mercury
Atmosphere	33·90	Feet of water
Atmosphere	14·70	Pounds per sq. in.
Barrels (oil)	42	Gallons
Boiler horsepower	33·475	B.T.U. per hour
B.T.U.	0·252	Calories
Centimetres	0·3937	Inches
Cubic feet	1,728	Cubic inches
Cubic feet of water	7·48	Gallons of water
Cubic feet of water	62·37	Pounds of water
Cubic feet per minute	0·1247	Gallons per second
Cubic metres	35·314	Cubic feet
Cubic metres	264·2	U.S. gallons
Feet	0·3048	Metres
Feet of water	0·881	Inches of mercury
Feet of water	62·37	Pounds per sq. ft.
Feet of water	0·4335	Pounds per sq. in.
Feet of water	0·0295	Atmospheres
Feet per minute	0·01136	Miles per hour
Feet per minute	0·01667	Feet per second
Gallons (U.S.)	0·1337	Cubic feet
Gallons (U.S.)	231	Cubic inches
Gallons (U.S.)	8·3453	Pounds of water
Gallons (Imperial)	277·3	Cubic Inches
Gallons (Imperial)	10	Pounds of water
Grams	0·03527	Ounces
Horsepower	33,000	Ft. lbs./min.
Horsepower	0·7457	Kilowatts
Horsepower (boiler)	33,471·9	B.T.U. per hour
Inches	2·54	Centimetres
Inches	25·4	Millimetres
Inches of mercury	1·131	Feet of water
Inches of mercury	0·4912	Pounds per sq. in.
Inches of water	0·03613	Pounds per sq. in.
Inches of water	5·202	Pounds per sq. ft.
Kilograms	2·2046	Pounds
Kilometres	0·6214	Miles
Kilowatts	1·341	Horsepower
Kilowatt-hours	3,415	B.T.U.
Litres	0·2642	U.S. gallons
Metres	39·37	Inches
Metres	3·2808	Feet
Miles	1·609	Kilometres
Millimetres	0·03937	Inches
Ounces	28·35	Grams
Pounds	0·4536	Kilograms
Pounds	7,000	Grains

CONVERSION FACTORS—Cont.

Multiply	*By*	*To Obtain*
Pounds of water	0·01602	Cubic feet
Pounds of water	27·68	Cubic inches
Pounds of water	0·1198	Gallons
Pounds per square in.	2·309	Feet of water
Pounds per square in.	2·0416	Inches of mercury
Tons of refrigeration	12,000	B.T.U. per hour
Tons (long)	2,240	Pounds
Tons, metric	2,204·6	Pounds
Tons (short)	2,000	Pounds
Watts	·5692	B.T.U. per minute
Watt-hours	3·415	B.T.U.

CONVERSION FACTORS

Cal./B.T.U. B.T.U./Cal.

B.T.U. = British Thermal Unit; Cal. = Kilocalory.

1 B.T.U.	=	0·252 Cal.
2 B.T.U's.	=	0·504 Cal.
3 B.T.U's.	=	0·756 Cal.
4 B.T.U's.	=	1·008 Cal.
5 B.T.U's.	=	1·260 Cal.
6 B.T.U's.	=	1·512 Cal.
7 B.T.U's.	=	1.764 Cal.
8 B.T.U's.	=	2·016 Cal.
9 B.T.U's.	=	2·268 Cal.
10 B.T.U's.	=	2·520 Cal.

1 B.T.U. = 778·16 ft. lb. = 0·252 Kilocalory

1 Cal.	=	3·968 B.T.U.
1 B.T.U./in.^{2}	=	390·6 Cal./m.^{2}
1 Cal./m.^{2}	=	0·003 B.T.U./in.^{2}
1 B.T.U./ft.^{2}	=	2·712 Cal./m.^{2}
1 Cal./m.^{2}	=	0·369 B.T.U./ft.^{2}
1 B.T.U./in.^{3}	=	5·149 Cal./m.^{3}
1 Cal./m.^{3}	=	0·194 B.T.U./in.^{3}
1 B.T.U./ft.^{3}	=	8·899 Cal./m.^{3}
1 Cal./m.^{3}	=	0·112 B.T.U./ft.^{3}
1 B.T.U./lb.	=	0·556 Cal./kg.
1 Cal./kg.	=	1·80 B.T.U./lb.
1 B.T.U./sq. in. °F. h	=	703·07 Cal./m.^{2} °C. h
1 Cal./m.^{2} °C. h	=	0·00142 B.T.U./sq. in. °F. h
1 B.T.U./sq. ft. °C. h	=	4·882 Cal./m.^{2} °C. h
1 Cal./m.^{2} °C. h	=	0·2048 B.T.U./sq. ft. °F. h
1 B.T.U./in. °F. h	=	17·858 Cal./m. °C. h
1 Cal./m. °C. h	=	0·056 B.T.U./in. °F. h

CONVERSION TABLES

lbs./kgs.

1 lb. = 16 ounces = 0·4535924 kgs.

Lbs.	*Kgs.*	*Lbs.*	*Kgs.*	*Lbs.*	*Kgs.*
1	0·45359	34	15·4221	67	30·3907
2	0·90718	35	15·8757	68	30·8443
3	1·36078	36	16·3293	69	31·2979
4	1·81437	37	16·7829	70	31·7515
5	2·26796	38	17·2365		
6	2·72155	39	17·6901	71	32·2051
7	3·17515	40	18·1437	72	32·6587
8	3·62874			73	33·1122
9	4·08233	41	18·5973	74	33·5658
10	4·53592	42	19·0509	75	34·0194
		43	19·5045	76	34·4730
11	4·98952	44	19·9581	77	34·9266
12	5·44311	45	20·4117	78	35·3802
13	5·89670	46	20·8653	79	35·8338
14	6·35029	47	21·3188	80	36·2874
15	6·80389	48	21·7724		
16	7·25748	49	22·2260	81	36·7410
17	7·71107	50	22·6796	82	37·1946
18	8·16466			83	37·6482
19	8·61826	51	23·1332	84	38·1018
20	9·07185	52	23·5868	85	38·5554
		53	24·0404	86	39·0089
21	9·52544	54	24·4940	87	39·4625
22	9·97903	55	24·9476	88	39·9161
23	10·4326	56	25·4012	89	40·3697
24	10·8862	57	25·8548	90	40·8233
25	11·3398	58	26·3084		
26	11·7934	59	26·7620	91	41·2769
27	12·2470	60	27·2155	92	41·7305
28	12·7006			93	42·1841
29	13·1542	61	27·6591	94	42·6377
30	13·6078	62	28·1227	95	43·0913
		63	28·5763	96	43·5449
31	14·0614	64	29·0299	97	43·9985
32	14·5150	65	29·4835	98	44·4521
33	14·9685	66	29·9371	99	44·9056
				100	45·3592

CONVERSION TABLES

p.s.i./Kg./cm.^{2}

p.s.i.	*kg./cm.*^{2}	*p.s.i.*	*kg./cm.*^{2}	*p.s.i.*	*kg./cm.*^{2}	*p.s.i*	*kg./cm.*^{2}
1	0·070	160	11·25	6,500	457·0	19,000	1,336
2	0·140	170	11·95	7,000	492·2	19,500	1,371
3	0·211	180	12·66	7,500	527·3	20,000	1,406
4	0·281	190	13·36	8,000	562·5		
5	0·352	200	14·06	8,500	597·6	20,500	1,441
6	0·422			9,000	632·8	21,000	1,476
7	0·492	300	21·09	9,500	667·9	21,500	1,511
8	0·562	400	28·12	10,000	703·1	22,000	1,547
9	0·633	500	35·15			22,500	1,582
10	0·703	600	42·19	11,000	773	23,000	1,617
		700	49·22	11,500	808	23,500	1,652
20	1·406	800	56·25	12,000	844	24,000	1,687
30	2·109	900	63·28	12,500	879	24,500	1,722
40	2·812	1,000	70·31	13,000	914	25,000	1,758
50	3·515			13,500	949		
60	4·219	1,500	105·5	14,000	984	25,500	1,793
70	4·922	2,000	140·6	14,500	1,019	26,000	1,828
80	5·625	2,500	175·8	15,000	1,055	26,500	1,863
90	6·328	3,000	210·9			27,000	1,898
100	7·031	3,500	246·1	15,500	1,090	27,500	1,933
		4,000	281·2	16,000	1,125	28,000	1,969
110	7·77	4,500	316·4	16,500	1,160	28,500	2,004
120	8·44	5,000	351·5	17,000	1,195	29,000	2,039
130	9·14			17,500	1,230	29,500	2,074
140	9·84	5,500	386·7	18,000	1,266	30,000	2,109
150	10·55	6,000	421·9	18,500	1,301		

CONVERSION TABLES

GALLONS/LITRES

American gallons into litres

1	3·785 litres
2	7·570 litres
3	11·355 litres
4	15·140 litres
5	18·925 litres
6	22·710 litres
7	26·495 litres
8	30·280 litres
9	34·065 litres
10	37·850 litres

Imperial gallons into litres

1	4·546 litres
2	9·092 litres
3	13·638 litres
4	18·184 litres
5	22·730 litres
6	27·276 litres
7	31·822 litres
8	36·368 litres
9	40·914 litres
10	45·460 litres

DENSITY CONVERSION TABLES

1 lb./cu. ft. = 0·0160185 g/cm.^{3}

lbs./ cu. ft.	*g/cm.*^{3}	*lbs./ cu. ft.*	*g/cm.*^{3}	*lbs./ cu. ft.*	*g/cm.*^{3}	*lbs./ cu. ft.*	*g/cm.*^{3}
1	0·016	51	0·817	101	1·618	151	2·419
2	0·032	52	0·833	102	1·634	152	2·435
3	0·048	53	0·849	103	1·650	153	2·451
4	0·064	54	0·865	104	1·666	154	2·467
5	0·080	55	0·881	105	1·682	155	2·483
6	0·096	56	0·897	106	1·698	156	2·499
7	0·112	57	0·913	107	1·714	157	2·515
8	0·128	58	0·929	108	1·730	158	2·531
9	0·144	59	0·945	109	1·746	159	2·547
10	0·160	60	0·961	110	1·762	160	2·563
11	0·176	61	0·977	111	1·778	161	2·579
12	0·192	62	0·993	112	1·794	162	2·595
13	0·208	63	1·009	113	1·810	163	2·611
14	0·224	64	1·025	114	1·826	164	2·627
15	0·240	65	1·041	115	1·842	165	2·643
16	0·256	66	1·057	116	1·858	166	2·659
17	0·272	67	1·073	117	1·874	167	2·675
18	0·288	68	1·089	118	1·890	168	2·691
19	0·304	69	1·105	119	1·906	169	2·707
20	0·320	70	1·121	120	1·922	170	2·723
21	0·336	71	1·137	121	1·938	171	2·739
22	0·352	72	1·153	122	1·954	172	2·755
23	0·368	73	1·169	123	1·970	173	2·771
24	0·384	74	1·185	124	1·986	174	2·787
25	0·401	75	1·202	125	2·003	175	2·804
26	0·417	76	1·218	126	2·019	176	2·820
27	0·433	77	1·234	127	2·035	177	2·836
28	0·449	78	1·250	128	2·051	178	2·852
29	0·465	79	1·266	129	2·067	179	2·868
30	0·481	80	1·281	130	2·083	180	2·884
31	0·497	81	1·298	131	2·099	181	2·900
32	0·513	82	1·314	132	2·115	182	2·916
33	0·529	83	1·330	133	2·131	183	2·932
34	0·545	84	1·346	134	2·147	184	2·948
35	0·561	85	1·362	135	2·163	185	2·964
36	0·577	86	1·378	136	2·179	186	2·980
37	0·593	87	1·394	137	2·195	187	2·996
38	0·609	88	1·410	138	2·211	188	3·012
39	0·625	89	1·426	139	2·227	189	3·028
40	0·641	90	1·442	140	2·243	190	3·044
41	0·657	91	1·458	141	2·259	191	3·060
42	0·673	92	1·473	142	2·275	192	3·076
43	0·689	93	1·490	143	2·291	193	3·092
44	0·705	94	1·506	144	2·307	194	3·108
45	0·721	95	1·522	145	2·323	195	3·124
46	0·737	96	1·538	146	2·339	196	3·140
47	0·753	97	1·554	147	2·355	197	3·156
48	0·769	98	1·570	148	2·371	198	3·172
49	0·785	99	1·586	149	2·387	199	3·188
50	0·801	100	1·602	150	2·403	200	3·204

TEMPERATURE CONVERSION TABLES

To convert:
° C. into ° F.: multiply by 9, divide by 5 and add 32.
° F. into ° C.: subtract 32, multiply by 5 and divide by 9.

C.		F.	C.		F.	C.		F.
−101	**−150**	−238	− 6·67	**20**	68·0	14·4	**58**	136·4
			− 6·11	**21**	69·8	15·0	**59**	138·2
− 95·6	**−140**	−220	− 5·56	**22**	71·6	15·6	**60**	140·0
− 90·0	**−130**	−202	− 5·00	**23**	73·4			
− 84·4	**−120**	−184	− 4·44	**24**	75·2	16·1	**61**	141·8
− 78·9	**−110**	−166	− 3·89	**25**	77·0	16·7	**62**	143·6
− 73·3	**−100**	−148	− 3·33	**26**	78·8	17·2	**63**	145·4
			− 2·78	**27**	80·6	17·8	**64**	147·2
− 67·8	**−90**	−130	− 2·22	**28**	82·4	18·3	**65**	149·0
− 62·2	**−80**	−112	− 1·67	**29**	84·2	18·9	**66**	150·8
− 56·7	**−70**	− 94	− 1·11	**30**	86·0	19·4	**67**	152·6
− 51·1	**−60**	− 76				20·0	**68**	154·4
− 45·6	**−50**	− 58	− 0·56	**31**	87·8	20·6	**69**	156·2
− 40·0	**−40**	− 40	0	**32**	89·6	21·1	**70**	158·0
− 34·4	**−30**	− 22	0·56	**33**	91·4			
− 28·9	**−20**	− 4	1·11	**34**	93·2	21·7	**71**	159·8
− 23·3	**−10**	14	1·67	**35**	95·0	22·2	**72**	161·6
− 17·8	**0**	32	2·22	**36**	96·8	22·8	**73**	163·4
			2·78	**37**	98·6	23·3	**74**	165·2
− 17·2	**1**	33·8	3·33	**38**	100·4	23·9	**75**	167·0
− 16·7	**2**	35·6	3·89	**39**	102·2	24·4	**76**	168·8
− 16·1	**3**	37·4	4·44	**40**	104·0	25·0	**77**	170·6
− 15·6	**4**	39·2	5·00	**41**	105·8	25·6	**78**	172·4
− 15·0	**5**	41·0	5·56	**42**	107·6	26·1	**79**	174·2
− 14·4	**6**	42·8	6·11	**43**	109·4	26·7	**80**	176·0
− 13·9	**7**	44·6	6·67	**44**	111·2			
− 13·3	**8**	46·4	7·22	**45**	113·0	27·2	**81**	177·8
− 12·8	**9**	48·2	7·78	**46**	114·8	27·8	**82**	179·6
− 12·2	**10**	50·0	8·33	**47**	116·6	28·3	**83**	181·4
			8·89	**48**	118·4	28·9	**84**	183·2
− 11·7	**11**	51·8	9·44	**49**	120·2	29·4	**85**	185·0
− 11·1	**12**	53·6	10·0	**50**	122·0	30·0	**86**	186·8
− 10·6	**13**	55·4				30·6	**87**	188·6
− 10·0	**14**	57·2	10·6	**51**	123·8	31·1	**88**	190·4
− 9·44	**15**	59·0	11·1	**52**	125·6	31·7	**89**	192·2
− 8·89	**16**	60·8	11·7	**53**	127·4	32·2	**90**	194·0
− 8·33	**17**	62·6	12·2	**54**	129·2			
− 7·78	**18**	64·4	12·8	**55**	131·0	32·8	**91**	195·8
− 7·22	**19**	66·2	13·3	**56**	132·8	33·3	**92**	197·6
			13·9	**57**	134·6	33·9	**93**	199·4

TEMPERATURE CONVERSION TABLES—*Cont.*

C.		F.	C.		F.	C.		F.
34·4	**94**	201·2	182	**360**	680	366	**690**	1,274
35·0	**95**	203·0	188	**370**	698	371	**700**	1,292
			193	**380**	716			
35·6	**96**	204·8	199	**390**	734	377	**710**	1,310
36·1	**97**	206·6	204	**400**	752	382	**720**	1,328
36·7	**98**	208·4				388	**730**	1,346
37·2	**99**	210·2	210	**410**	770	393	**740**	1,364
37·8	**100**	212·0	216	**420**	788	399	**750**	1,382
			221	**430**	806			
43	**110**	230	227	**440**	824	404	**760**	1,400
49	**120**	248	232	**450**	842	410	**770**	1,418
54	**130**	266				416	**780**	1,436
60	**140**	284	238	**460**	860	421	**790**	1,454
66	**150**	302	243	**470**	878	427	**800**	1,472
			249	**480**	896			
71	**160**	320	254	**490**	914	432	**810**	1,490
77	**170**	338	260	**500**	932	438	**820**	1,508
82	**180**	356				443	**830**	1,526
88	**190**	374	266	**510**	950	449	**840**	1,544
93	**200**	392	271	**520**	968	454	**850**	1,562
			277	**530**	986			
99	**210**	410	282	**540**	1,004	460	**860**	1,580
104	**220**	428	288	**550**	1,022	466	**870**	1,598
110	**230**	446				471	**880**	1,616
116	**240**	464	293	**560**	1,040	477	**890**	1,634
121	**250**	482	299	**570**	1,058	482	**900**	1,652
			304	**580**	1,076			
127	**260**	500	310	**590**	1,094	488	**910**	1,670
132	**270**	518	316	**600**	1,112	493	**920**	1,688
138	**280**	536				499	**930**	1,706
143	**290**	554	321	**610**	1,130	504	**940**	1,724
149	**300**	572	327	**620**	1,148	510	**950**	1,742
			332	**630**	1,166			
154	**310**	590	338	**640**	1,184	516	**960**	1,760
160	**320**	608	343	**650**	1,202	521	**970**	1,778
166	**330**	626				527	**980**	1,796
171	**340**	644	349	**660**	1,220	532	**990**	1,814
177	**350**	662	354	**670**	1,238	538	**1,000**	1,832
			360	**680**	1,256			

ADDRESSES OF PATENT OFFICES

Belgium. Administration du Commerce, Service de la Propriété, Industrielle et Commerciale, 19 Rue de la Loi, Brussels.
France. Direction de la Propriété Industrielle, 26 bis Rue de Leningrad, Paris, -8e.
(*Western*) *Germany.* German Patent Office, Museuminsel 1, 13(b), München 26.
(*Eastern*) *Germany.* Amt für Erfindungs-und Patentwesen Patentabteilung, Berlin W.8, Mohrenstrasse 37B, D.D.R.
Great Britain. Patent Office (Board of Trade), Southampton Buildings, Chancery Lane, London, W.C.2.
Holland. Bureau voor den Industriele Eigendom, Willen Witsenplein 6, 's-Gravenhage.
Italy. Ministero delle Industria e del Commercio, Centrali dei Brevetti, Roma.
Sweden. Kungl. Patent-och, Registrerings-Verkert, Stockholm.
Switzerland. Bureau Fédéral de la Propriété Intellectuelle, Berne.
U.S.A. Commissioner of Patents, Washington, 25, D.C.

INFORMATION ON PLASTICS

The number of journals which deal more or less exclusively with plastics has grown tremendously during the last few years, and today it is almost impossible for any individual person to keep up-to-date by reading all these journals. Most people, therefore, read a few selected journals and rely more and more on abstracts, to make certain that they do not miss papers and publications which have appeared in other journals, especially if they are not readily accessible. The list of journals given in this book gives the names and addresses of Plastic Journals published all over the world, but does not include so-called house journals.

The B.P.F. abstracts issued by the British Plastics Federation report on developments, patents, papers and other matters related to the plastics industry. These abstracts are compiled from over 180 journals; British, American, Canadian, French, German and Swiss Patents on inventions in the field of plastics are also abstracted. These abstracts are primarily published for the benefit of the members of the Federation, but they are also available to non-members by subscription.

JOURNALS

MONTHLY.	*ADHESIVES & RESINS* (*E*).	A. S. O'Connor & Co. Ltd., 331 Gray's Inn Road, W.C.1.
MONTHLY.	*APPLIED PLASTICS* (*E*).	The Scientific Press Ltd., 11a Gloucester Road, S.W.7.
MONTHLY.	*AUSTRALIAN PLASTICS* (*E*).	Australian Trade Publications Ltd., 171 Sussex Street, Sydney, Australia.
MONTHLY.	*BRITISH PLASTICS* (*E*).	Iliffe & Sons Ltd., Dorset House, Stamford Street, S.E.1.

MONTHLY.	*BRITISH PLASTICS FEDERATION ABSTRACTS* (*E*).	British Plastics Federation, 47–48 Piccadilly, W.1.
MONTHLY.	*CANADIAN PLASTICS* (*E*).	The Monetary Times Printing Co. of Canada Ltd., Monetary Times Building, 341 Church Street, Toronto 2, Ontario.
FORTNIGHTLY.	*IL GIORNALE DELLE MATERIE PLASTICHE* (*I*).	Direzione E. Amministrazione, Corso Genova, 15, Milano, Italy.
MONTHLY.	*INDIAN PLASTICS REVIEW* (*E*).	Plastics & Machinery Distributors, 4 Upper Chitpur Road, Post Bag 6703, Calcutta 7.
MONTHLY.	*INDUSTRIE DES PLASTIQUES MODERNES* (*F*).	Société de Chimie Industrielle, La Presse Documentaire, 28 rue Saint Dominique, Paris VII, France.
SEVEN VOLUMES ANNUALLY.	*JOURNAL OF POLYMER SCIENCE* (*E*).	Interscience Publishers Inc., 250 5th Avenue, New York 1, N.Y. and 88/90 Chancery Lane, W.C.2.
MONTHLY.	*KUNSTSTOFFE* (*G*).	Carl Hanser Zeitschriftenverlag G.m.b.H., München, 27, Germany.
MONTHLY.	*KUNSTSTOFF-BERATER* (*G*).	Umschau Verlag K.G. (Inh. Breidenstein), Frankfurt-am-Main, Germany.
THREE TIMES PER YEAR.	*KUNSTSTOFFE PLASTICS* (*G*).	Vogt-schild Ltd., Soleure, Switzerland.
MONTHLY.	*KUNSTSTOFF-RUNDSCHAU* (*G*).	Verlag und Anzeigenverwaltung, Brunke Garrels, Verlagsbuchhandlung, Hamburg-Wandsbek, Schlossstrasse 2-6, Germany.
MONTHLY.	*MATERIE PLASTICHE* (*I*).	8, via Farneti, Milano, Italy.
MONTHLY.	*MODERN PLASTICS* (*E*).	Breskin Publications, Inc., 575 Madison Avenue, N.Y.22.
MONTHLY.	*OSTERREICHISCHE PLASTIC-RUNDSCHAU* (*G*).	Zeitschriftenverlag Ployer & Co., Aegidigasse 5, Wien VI, Austria.
MONTHLY.	*OFFICIEL DES MATIERES PLASTIQUES* (*F*).	12 Rue de l'Isly, Paris 8.
MONTHLY.	*PENSEZ PLASTIQUES* (*F*).	Les Editions de Berne et Cie, 11 Boulevard des Batignolles, Paris 8, France.
MONTHLY.	*PLASTE UND KAUTSCHUK* (*G*).	Veb Verlag Technik, Oranienburger Strasse 13/14, Berlin C.2, Germany.
MONTHLY.	*PLASTIC* (*D*).	Danish Technical Press, 45 Bredgade, Copenhagen K, Denmark.
MONTHLY.	*PLASTICA* (*H*).	Kunststoffeninstituut T.N.O., Julianalaan 134, Delft, Holland.
EVERY 2 MONTHS.	*PLASTICOS* (*S*).	Cangallo 1642 Escr. 1, Buenos Aires, Argentina.
MONTHLY.	*PLASTICS* (*E*).	Temple Press Ltd., Bowling Green Lane, E.C.1.
EVERY 2 MONTHS.	*PLASTICS & PAINT* (*E*).	Odhams Press, South Africa (Pty.) Ltd., Trust House, Thibault Square, P.O. Box 4245, Cape Town, S.A.

MONTHLY.	*PLASTICS INDUSTRY* (*E*).	Vincent Edwards & Co., 342 Madison Avenue, N.Y.16.
MONTHLY.	*PLASTICS INDUSTRY NEWS* (*JAPAN*) (*E*).	Institute of Polymer Industry Inc., 23-Shiba Tamura-cho 5, Minato-ku, Tokyo, Japan.
MONTHLY.	*PLASTICS TECHNOLOGY* (*E*).	Plastics Technology Publishing Corp., Division of Bill Brothers Publishing Corp., Third and Hunting Park Avenue, Philadelphia, Pa.
FORTNIGHTLY.	*PLASTIQUES INFORMATIONS* (*F*).	94 rue Saint Lazare, Paris 9e.
MONTHLY.	*PLASTNYTT* (*N*).	Norsk Plastforeining, Universitetsgaten 14, Oslo, Norway.
MONTHLY.	*PLASTVARLDEN* (*Sw*).	Klara V Kyrkogata 7, Box 254, Stockholm 1.
MONTHLY.	*DER PLASTVERARBEITER* (*G*).	Rudolf Zechner Verlag, G.m.b.H., Speyer/Rh., Moerschgasse 33/35, Germany.
EVERY 2 MONTHS.	*POLIPLASTI* (*I*).	ET/AS Editrice, Via Mantegna 6, Milan.
MONTHLY.	*PRACTICAL PLASTICS* (*E*).	A. M. and D. C. Johnston-Bell, Box 4850, G.P.O., Sydney.
MONTHLY.	*REINFORCED PLASTICS* (*E*).	Craftsman Publications Ltd., 9 New St. Square, London, E.C.4.
MONTHLY.	*RUBBER & PLASTICS AGE* (*E*).	Gaywood House, Gt. Peter Street, Westminster, London, S.W.1.
WEEKLY.	*RUBBER JOURNAL & INTERNATIONAL PLASTICS* (*E*).	Maclaren & Sons Ltd., Maclaren House, 131 Great Suffolk Street, S.E.1.
EVERY 2 MONTHS.	*REVISTA DE PLASTICOS* (*S*).	Departamento de Plasticos y Tecnologia del Caucho Patronato 'Juan de la Cierva' de Investigacion Tecnica, Redaccion y Administracion, Serrano 119, Madrid, Spain.
MONTHLY.	*RESINS, RUBBERS & PLASTICS ABSTRACT SERVICE* (*E*).	Interscience Publishers, Inc., 250 5th Avenue, New York 1, N.Y.
MONTHLY.	*S.P.E. JOURNAL* (*E*).	The Society of Plastics Engineers Inc., 65 Prospect Street, Stamford, Connecticut, U.S.A.
IRREGULAR.	*SWEDISH PLASTICS FEDERATION TECHNICAL PAPERS* (*Sw*).	Svenska Plastforeningen, Karlavagen 43 II, Stockholm, Sweden.
MONTHLY.	*TRANSFORMATIONS DES PLASTIQUES* (*F*).	G. Glachant, Depot Legal, Imprimerie G. Frère, Tourcoing-Paris.
MONTHLY.	*WESTERN PLASTICS* (*E*).	Western Business Publications, 274 Brannan Street, San Francisco 7, California.

Abbreviations used for languages in which printed:

E. English	*I.* Italian	*H.* Dutch
F. French	*S.* Spanish	*D.* Danish
G. German	*Sw.* Swedish	*N.* Norwegian

STANDARDS FOR POLYVINYL CHLORIDE

BELGIUM

NBN 396 (1955) Feuilles en chlorure de polyvinyle ou copolymères pour imperméables.
(Thin sheet for rainwear).

GERMANY

DIN 1910 (1954) Bl. 1. Schweissen. Schweissverfahren. Allgemeine Einteilung.
Welding of thermoplastic materials—welding processes general classification.

DIN 8062 (1941) Kunststoffrohre aus Polyvinylchlorid (Rohrtyp).
P.V.C. pipes.

DIN 8063 (1941) Kunststoff-Rohrbogen aus Polyvinylchlorid (Rohrtyp).
P.V.C. pipe bends.

DIN 8064 (1941) Kunststoff-Winkel aus Polyvinylchlorid (Rohrtyp).
P.V.C. elbows.

DIN 8065 (1941) Kunststoff-T-Stücke aus Polyvinylchlorid (Rohrtyp).
P.V.C. T-Pieces.

DIN 8066 (1947) Rohrverschraubungen fuer Kunststoffrohre aus Polyvinylchlorid (Rohrtyp).
P.V.C. screw couplings and joints.

DIN 8067 (1941) Loser Flansch mit Bund fuer Kunststoffrohr-Verbindungen aus Polyvinylchlorid (Rohrtyp) mit Flanschanschlussmassen nach DIN 2501.
P.V.C. loose flanges.

DIN 16920 (1954) Klebstoffe, Richtlinien für die Einteilung.
Cements (Classification).

DIN 16921 (1954) (Vornorm) Klebstoffe, Klebstoffverarbeitung, Begriffe.
Tentative standards for cements and their use.

DIN 16927 Anforderungen für Polyvinylchlorid-Tafeln (P.V.C.-hart).
Anforderungen für Polyvinylchlorid-Rohre (P.V.C.-hart).
P.V.C. sheets (unplasticized).
P.V.C. pipes (unplasticized).

DIN 16928 (1957) Kunststoffrohre aus Polyvinylchlorid (Rohrtyp).
Eigenschaften und Richtlinien fuer die Verwendung.
P.V.C. pipes—properties and suggestions for their use.

DIN 16929 (1957) Bl. 1—Entwurf—Polyvinylchlorid-Erzeugnisse (P.V.C.-hart). Rohre. Technische Lieferbedingungen.

(1957) Bl. 2—Entwurf—Polyvinylchlorid-Erzeugnisse (P.V.C.-hart), Tafeln, Rohre, Verarbeitsungsrichtlinien.

(1957) Bl. 3.—Entwurf—Polyvinylchlorid-Erzeugnisse (P.V.C.-hart), Tafeln, Rohre, Anwendungsrichtlinien.

No. 1 (Tentative standard) P.V.C. pipes (unplasticized) Dimensions, tolerances, etc.

No. 2 (Tentative standard) P.V.C. sheets, pipes, etc. (unplasticized)—fabrication methods.

No. 3 (Tentative standard) P.V.C. sheets, pipes, etc. unplasticized—applications.

DIN 16930 (1955) Kunststoffe. Schweissen von hartem Polyvinylchlorid (P.V.C.-hart). Richtlinien.
Welding of rigid, unplasticized P.V.C.

DIN 16931 (1956) Kunststoffe. Schweissen von weichem Polyvinylchlorid (P.V.C.-weich). Richtlinien.
Welding of plasticized P.V.C.

Note: The German titles are quoted in full. An abbreviated translation into English is given below each individual standard.

GREAT BRITAIN

B.S. 1231 (1945) P.V.C. cables and cords for switchboard panel wiring.
B.S. 1763 (1956) Thin P.V.C. sheeting (flexible, unsupported).
B.S. 1774 (1951) Part I. Fabrication of rainwear from polyvinyl chloride sheeting.
B.S. 1776 (1951) Fabrication of lightweight articles (other than rainwear) from polyvinyl chloride sheeting.
B.S. 2004 (1955) Polyvinyl chloride insulated flexible cords for electric power and lighting.
B.S. 2571 (1955) Flexible polyvinyl chloride (P.V.C.) extrusion compounds.
B.S. 2601, 2602, 2603 (1953) Coated fabrics (leather-cloths) for unsupported furniture.
B.S. 2739 (1956) Thick P.V.C. sheeting (flexible, unsupported).
B.S. 2746 (1956) P.V.C. insulation of sheath and electric cables.
In preparation: Standards for rigid P.V.C. pipes.
Standards for flexible P.V.C. pipes.

HOLLAND

V3031 (1953) Keuringseisen en methodes voor regenkleding vervaardigd uit (Tentative Standard).

JAPAN

JIS.K. 6723 (1955) Non-rigid polyvinyl chloride compound.
JIS.K. 6732 (1953) Polyvinyl chloride film for agriculture.
JIS.K. 6741 (1957) Rigid polyvinyl chloride pipes.

SOUTH AFRICA

SABS 150 (1957) Polyvinyl chloride (P.V.C.) insulated electrical conductors.
SABS 531 (1956) Polyvinyl chloride containers for reference books.

SPAIN

UNE 53 051 (1956) Materiales plásticos, plásticos no rididos de policloruro de vinilo, especificiones.

SWITZERLAND

VSM 18380 (Vornorm 1956) Rohrleitungen. Thermoplast-Rohre aus Hart-Polyvinylchlorid für Flüssigkeiten und Gase. Nenndruck 1. (Tentative Standards).
VSM 18381 (Vornorm 1956) Rohrleitungen. Thermoplast-Rohre aus Hart-Polyvinylchlorid für Flüssigkeiten und Gase. Nenndruck 6 und 10 (Tentative Standards).
SEV 184 (1950) Mit Änderung 1956 Vorschriften für Leiter mit thermoplastischer Kunststoffisolation auf Polyvinylchlorid-basis. T-Leitervorschriften des SEV. (Tentative Standards).

U.S.A.

AMS.3630B	(1955)	Plastic extrusions, flexible P.V.C.
AMS.3631	(1957)	Plastic extrusions, flexible high temperature P.V.C.
C.S.192	(1953)	General purpose vinyl plastic film.
C.S.201	(1955)	Rigid polyvinyl chloride sheets.
L.P.375a	(1958)	Plastic film, flexible polyvinyl chloride.
L.P 510	(1955)	Plastic sheet, modified unplasticized polyvinyl chloride, rigid.
L.P.550	(1954)	Plastic polyvinyl chloride cartographic sheeting.
L.T.751	(1952)	Floor tiles, vinyl plastics.
L.V.345	(1952)	Vinyl chloride polymer and copolymer rigid, moulded plastics.
L.V.351	(1957)	Vinyl chloride polymer and copolymer rigid sheets.
NF.T. 54–004	(1957)	Thin P.V.C. sheets: makeup and dimensions.

NUMBER OF RUNS REQUIRED FOR A BUTT-WELD IN RIGID P.V.C. SHEET

Thickness of Sheet	Single 'V' Butt-weld		Double 'V' Butt-weld		
	At Root	Following up	At Root	Following up	
1·6 mm. $\frac{1}{16}$ in.	1st run $\frac{1}{32}$ in. F.R.	—	not practised	—	
3·2 mm. $\frac{1}{8}$ in.	1st run $\frac{3}{32}$ in. F.R. —	2-3 runs $\frac{1}{8}$ in. F.R. —	1st run $\frac{3}{32}$ in. F.R. —	1 run $\frac{1}{8}$ in. F.R. 1 run $\frac{1}{8}$ in. F.R.	Top part Lower part
6·35 mm. $\frac{1}{4}$ in.	1st run $\frac{3}{32}$ in. F.R. —	5-8 runs $\frac{1}{8}$ in. F.R. —	1st run $\frac{3}{32}$ in. F.R. —	2-3 runs $\frac{1}{8}$ in. F.R. 2-3 runs $\frac{1}{8}$ in. F.R.	Top part Lower part
9·5 mm. $\frac{3}{8}$ in.	1st run $\frac{3}{32}$ in. F.R. —	8-10 runs $\frac{1}{8}$ in. F.R. —	1st run $\frac{3}{32}$ in. F.R. —	6 runs $\frac{1}{8}$ in. F.R. 6 runs $\frac{1}{8}$ in. F.R.	Top part Lower part

F.R.=Filler rod.

WEIGHT OF RIGID P.V.C. SHEETS IN VARIOUS THICKNESSES

sq. ft.	$\frac{1}{16}$ in.	$\frac{1}{8}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.	$\frac{3}{8}$ in.	$\frac{1}{2}$ in.	$\frac{3}{4}$ in.	1 in.
1	0·48	0·96	1·44	1·92	2·40	2·88	3·84	5·76	7·68
2	0·96	1·92	2·88	3·84	4·80	5·76	7·68	11·52	15·36
3	1·44	2·88	4·32	5·76	7·20	8·64	11·52	17·28	23·04
4	1·92	3·84	5·76	7·68	9·60	11·52	15·36	23·04	30·72
5	2·40	4·80	7·20	9·60	12·00	14·40	19·20	28·80	38·40
6	2·88	5·76	8·64	11·52	14·40	17·28	23·04	34·56	46·08
7	3·36	6·72	10·08	13·44	16·80	20·16	26·88	40·32	53·76
8	3·84	7·68	11·52	15·36	19·20	23·04	30·72	46·08	61·44
9	4·32	8·64	12·96	17·28	21·60	25·92	34·56	51·84	69·12
10	4·80	9·60	14·40	19·20	24·00	28·80	38·40	57·60	76·80

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